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The ADVANCEMENT OF SCIENCE

Vol. V, No. 17

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REPORT OF A DISCUSSION

Chemical Resources and Industries of Scotland
REPORT OF A DISCUSSION

Operational Research
BY PROF. P. M. S. BLACKETT, F.R.S.

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OFFICE

SECTION

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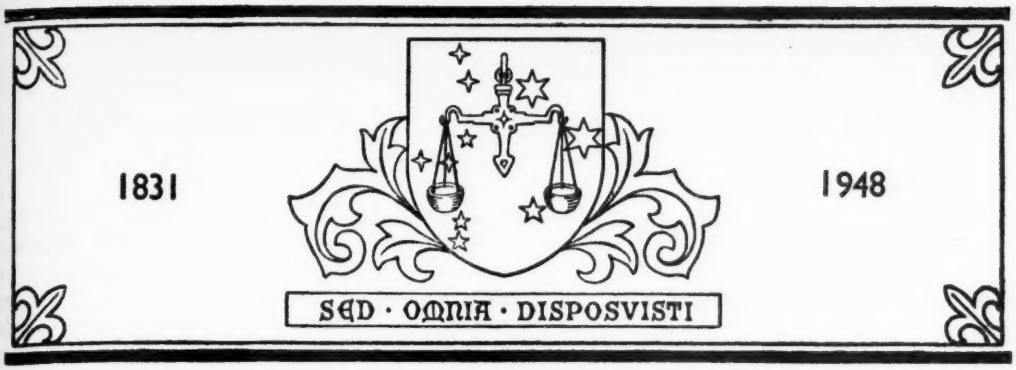

THE ADVANCEMENT OF SCIENCE

VOL. V, No. 17 APRIL, 1948

CONTENTS

PAGE

OFFICERS AND COUNCIL 1

SECTIONAL OFFICERS 2

THE PLACE OF UNIVERSITIES IN THE COMMUNITY 4
Implications of the Barlow Report: Lord Simon of Wythenshawe, 4—Prof. P. M. S. Blackett, F.R.S., 4—Dr. Eric James, 6—Sir John Lennard-Jones, K.B.E., F.R.S., 7—Discussion, 8. *Research and Organisation:* Sir Henry Dale, O.M., G.B.E., F.R.S., 11—Prof. M. Polyani, F.R.S., 13—Prof. J. D. Bernal, F.R.S., 15—Discussion, 18

CHEMICAL RESOURCES AND INDUSTRIES OF SCOTLAND .....
Report of a Discussion arranged by Section B (Chemistry), Dundee, 1947. 20

OPERATIONAL RESEARCH 26
By Prof. P. M. S. Blackett, F.R.S.

PAGE

SUPPLY AND UTILISATION OF COAL 38
Record of Meetings, Dundee, 1947.

CULTURAL CHANGE 48
Edited by Prof. Daryll Forde. Dr. A. I. Richards, 48—Dr. L. P. Mair, 51—Dr. K. L. Little, 52—Prof. C. von Fürer-Haimendorf, 53

CONFERENCE OF DELEGATES OF CORRESPONDING SOCIETIES, DUNDEE, 1947 56

THE NATURAL HISTORY SOCIETY 57
Address by Dr. J. Ramsbottom.

DEPLETION OF WILD ANIMAL POPULATIONS 64
By Prof. James Ritchie and others.

MATHEMATICAL TABLES 67
Report of Committee

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THE PLACE OF UNIVERSITIES IN THE COMMUNITY

On May 10, 1947, the British Association's Division for Social and International Relations of Science held a conference in the University of Manchester on The Place of Universities in the Community. The objects of the Conference were to discuss some important problems arising from post-war expansion of the universities, to focus attention on some of the more immediate difficulties and, if possible, to propose some remedies. The Conference was held in two sessions of which the Chairmen were Lord Simon of Wythenshawe and Sir Henry Dale respectively. The following is a report of the discussion.

First Session

IMPLICATIONS OF THE BARLOW REPORT

CHAIRMAN: LORD SIMON OF WYTHENSHAWE

Lord Simon said that universities were going through development which might fairly be called revolutionary and as most university teachers and administrators were overloaded as a result of great expansion, this conference was welcomed as providing an admirable opportunity to consider what was taking place.

In the past six years there had been no less than six separate Reports arising from enquiries instigated by Ministers and dealing with aspects of universities affairs, all of them closely affecting university work. The first was the Goodenough Report on Medical Education, which had revolutionised conditions of teachers and part-timers. The second was the report of the Teviot Committee on Dental Research. The third was the Report of the McNair Committee appointed by the Minister of Education to deal with the question of the training of teachers. The fourth was the Report of the Clapham Committee which recommended expenditure of about a quarter of a million pounds for the development of the social sciences in universities. The fifth was the Scarborough Report, which recommended expenditure of about a quarter of a million pounds to begin with, and half a million later, to permit universities to study the cultures and languages of five oriental civilisations in Asia, Russia and Africa. Finally, there was the Barlow Report on Scientific Manpower which recommended doubling the number of scientists produced by the universities in 10 years.

The next important development was the action taken by the Chancellor of the Exchequer (Mr. Dalton) to strengthen the University Grants Committee, to give it, for the first time, something approaching an adequate staff, to appoint a scientist as a whole-time member of that staff and, most important of all, to give the Committee positive terms of reference to ensure that the universities were in all fields adequate to the national needs.

Before the second world war, the income of universities from sources other than the Government was about four million pounds a year, and that seemed unlikely to increase substantially. Government grants had increased from two millions before the late war to a rate of nine millions in the first post-war year, rising ultimately to sixteen millions. At this rate, some 80 per cent. of the total income of universities would come from the Government and this high proportion of Government assistance had some obvious dangers affecting the independence of universities.

In conclusion Lord Simon said that in Manchester University the effect of the encouragement and of the help the Government had given was that members of the University looked forward to the time when the city would have one of the finest sites for a university in the whole world. The city and the university together had developed an imaginative plan, covering 300 acres, which envisaged a cultural centre that no university would have the courage to build without the support given by the Government to those who were trying to carry out the inspiring new ideals of town planning.

Prof. P. M. S. Blackett, F.R.S.

Prof. Blackett gave an account of some of the pre-history of the Barlow Report and how it came into being, discussed some of the criticisms of the report and made suggestions as to what might be done to follow it up in the future.

During the war there was a wide realisation that at least twice as many scientists could be usefully employed in various

capacities as were, in fact, available. Consequently the question of the supply of scientists became the subject of much discussion and many studies. One of the first of those studies was a report on 'Science in the Universities' which was published by the Association of Scientific Workers in March 1945 and discussed the size of the universities in relation to the probable real needs of the country. In the same year came Sir Ernest Simon's valuable pamphlet on the development of British universities in which a comparison was made with American universities. Then in 1945 under the 'Caretaker' Government, the Service Departments started to plan their future civilian Research Establishments. They estimated their requirements at nearly as many scientists as they had during the war and which would be obtainable only at the expense of universities, schools, industrial research, etc.

After the end of the war, the problem of export trade became of paramount importance. It was clear that a serious bottleneck in the production of first-class goods for export was the shortage of technical intelligentsia in the country—that is, the engineers and scientists. Thus it became evident that more scientists were wanted, and that the universities must be expanded first.

A Committee under Lord Cherwell was set up by the 'Caretaker' Government, and started an investigation at a departmental level of the supply and the demand for scientists. Next, the Royal Society, after discussing the problem, and the findings of the report ('Science The Endless Frontier') by Vannevar Bush to the President of the United States in the Spring of 1945, made representations to the Treasury that an investigation was needed.

The final result was that the Lord President of the Council appointed the Barlow Committee under the presidency of Sir Alan Barlow of the Treasury. This was a small Committee consisting of five independent members, together with a few civil servants, which had the terms of reference to investigate the need for and the possible supply of scientists. They reported a few months later that for many years ahead the demand for scientists of all branches was likely to exceed the supply. They were not in a position to estimate numerical details in relation to supply and demand very far ahead, nor in detail for the different subjects, and this was one of the questions which needed much following up.

The figures very roughly were that, as far as could be made out, there were about 55,000 scientists in the United Kingdom at that time: scientists being taken as including everyone with a higher degree or its equivalent in science or allied subjects. To estimate the demand was very difficult, but it was at least 70,000 in 1950 and 90,000 in 1955. The Committee recommended, in effect, that the output of scientists from the universities should be doubled as soon as possible; and at any rate within 10 years.

If the Committee were right about the large demand, were they right about there being an adequate supply of talent available? Was there available in the country the talent which would allow the desired expansion without a reduction of standards? The Committee considered the available evidence including the results of the intelligence testing which was widely used by the Services during the war. They came to the conclusion that, on the available evidence, there was ample reserve of talent in the country if it could be brought to the level of education for entry into the university. It was not asserted that the educational ladder from elementary to secondary school and on to the university was adequate to deal with the increased numbers; but it was asserted that the requisite talent was available.

It appeared that about 5 per cent. of the population had an Intelligence Quotient (I.Q.) equal to that of the top half of the university students in Manchester. Since nearly 2 per cent. of an age group now reached the university, the top half of university students amounted to 1 per cent. of the population. Thus broadly speaking, these experimental figures showed that in each age group there were four people outside the university with as high an I.Q. as the top half of the students now in the universities. A number of these people were probably not temperamentally suited for university life; many wanted to take up other professional careers; but it seemed clear as far as the evidence went, and there was much personal experience to support it, that there was ample reserve of talent to allow both the doubling of the input to the universities, and the maintenance, or even an increase, of standards.

A possible criticism of the Barlow Report was that the demand might not actually materialise. It was only too well known from economic history that there could be a real demand for goods and at the same time a lack of sufficient numbers of people able to buy the goods; the same might be the case in the scientific profession. There might, in fact, be a period of professional unemployment.

One of the reasons why the Barlow Committee took an optimistic view was this: firstly, they drew attention to the fact that the Government had pledged itself to a policy of full employment in the country as

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a whole. If the Government or their successors failed markedly to implement this, then so many political events would occur that some middle class unemployment would be but a small part of the country's troubles. Under certain conditions there might be full employment of wage earners but unemployment among technicians. The Government, however, should be able to cope with this situation, for the demands of Government Departments for scientists, at any rate in many fields, much exceeded the supply. A great amount of research demanded by the Services and certain Government Departments after the war, had to be stopped because of this lack of scientists. In the event of more scientists being produced than could be absorbed in industry the Government could and should again increase its own scientific establishments.

Furthermore, there was the question of what proportion of the teachers of this country should have university degrees. The National Union of Teachers held the view that all teachers should have university degrees or their equivalent. With the rapid expansion of the teaching profession due to the raising of the school-leaving age, the N.U.T. accepted a large dilution with the result that the percentage of graduates in the teaching profession could not be more than 20 per cent. Most people would agree that the percentage should be much larger. So there was a big potential demand for scientists which the Government ought to make a real demand as soon as possible, by gradually raising the percentage of teachers with a university training.

In private industry it was more difficult to guess the prospects. Some big firms, particularly some electrical and chemical firms, had fine research establishments, but there were many others, including a large number of small firms, which were flagrantly unscientific. Such firms must be induced in some way to expand their scientific staffs.

If the supply and demand for scientists in each field were to match, it seemed essential that the Barlow Report be followed up by continuous and detailed study. It was essential to know much more of the statistical situation regarding the supply of young scientists : e.g. from what income groups they came, the types of schools attended, the amount of financial support required, how many went into teaching, how many became Government servants, how many went into industry, and so on. What was required, in fact, was a continuous study of what was happening in the scientific profession.

In conclusion Prof. Blackett said that at the back of some peoples' minds was the fact that the Barlow Committee had approached the problem from the mainly utilitarian angle of how many scientists the country needed. Few people, and especially few professional people, looked on the universities from this point of view alone. Most middle class and professional families expected their children to have the right to a university education irrespective of the profession they intended to follow afterwards. This raised the problem of what fraction of the population should go to a university. Should university education be limited to those who needed university training for their professional career? His own view was, on the contrary, that, quite apart from the economic necessity of becoming a technically advanced nation, we must also strive to become a highly educated nation ; and, consequently, that a large fraction of the population should have the opportunity of a university education. In England only 2 per cent. of the population were educated to 21 years of age, as compared with 15 per cent. in America, and he thought that the modest recommendation to double university output in 10 years would only be considered as a beginning.

Dr. Eric James

DR. JAMES said that, in his view, one of the greatest weaknesses of the Barlow Report was that no evidence was taken from the schools and there were gaps in the Report, as Prof. Blackett has said. These rested on ignorance of the schools' capacity to deal with this particular problem. University students did not grow on trees ready-made at the age of 18. They were the product of education in the grammar schools and a new assessment was required in which the capacity of the schools to produce trained scientists, before they came to the universities, was fully examined and estimated.

The whole problem of resources of ability was one which affected the schools and on which the schools ought to be consulted. The first priority in tackling this problem was to find out at what stage in the educational process wastage of this fundamental fount of intelligence and national talent was taking place. Was it at the age of 11-plus on selection for secondary education, or at the age of 15-plus or 16-plus after School Certificate, or at the age of 18-plus when young people who ought to go to the universities were not doing so? An authoritative investigation of that problem was urgently required.

The Barlow Report emphasised the need for academic research, but the failure to recognise the basic position of the schools meant that an insufficient allowance was

made for trained science teachers. The critical position of the grammar schools could not be overstressed, for highly trained scientific teachers in schools were essential to produce what the universities needed. The school teacher was the prerequisite for the success of industrial scientific schemes, or academic research, or anything else; in other words, the universities must see that a proper proportion of their scientific graduates took up teaching as a career or the whole edifice would fall to the ground.

Dr. James went on to say that the work of the universities rested on the quality of the work that was done in the schools. The whole existence of the universities, the whole production of trained scientists, depended on the maintenance of quality in the grammar schools. The teachers in schools would like to feel that the universities were more actively concerned over general educational problems than they were at the moment and taking a more informed interest in them in order to maintain the standards on which alone university education and the output of trained graduates could rest.

In conclusion Dr. James said that he would like to hear some comment on a fundamental question, namely, the general education of the scientist.[1] If university graduates, going into industry or research, were to fit into the new scientific set-up, they would have to be people with broad knowledge, a social consciousness and a sense of social responsibility. How was this to be achieved? It was partly a school problem, and partly a university problem. What did the universities expect the equipment to be of a boy or girl of 18 coming to the university to study science? There was too much woolly thinking on this problem, and greater concreteness was required in thoughts about what was meant by the proper general education for an academically-gifted individual of 18-plus, and the schools would welcome any guidance which could be got from the universities.

Sir John Lennard-Jones, K.B.E., F.R.S.

SIR JOHN LENNARD-JONES said he thought it would be generally conceded that the universities occupied a unique place in the national life because they stood between the eager, intelligent youth of the country and the broad stream of adult affairs. That carried with it responsibilities and duties as well as privileges. The universities had first and foremost a duty to the individual, a duty to provide the young student with a means to knowledge, a duty to help him to educate himself, a duty to equip him for citizenship in its broadest sense. The universities also had a duty to the State. They had under their influence, at the formative period of their lives, the cream of the nation's manhood. This was a great responsibility, but also a challenge to service. It took a long time to train a man for the professions; it was costly, both in time, and money, and how tragic it was, therefore, when, after a long discipline of learning, graduates failed to find the opportunity for appropriate employment in the profession for which they had fitted themselves. This was tragic not only for the individual, but also for the State, for talent was lost in the process.

The universities were now setting about the task of increasing the number of graduates. Should they not at the same time endeavour to relate supply to demand? This implied a knowledge of the needs of the community, of future trends in the nation's economic life, and the question of the demand for trained workers in particular fields. The universities should be fully and accurately informed about the openings for trained workers in all the professions, in industry, and in Government service. This information was to some extent obtained now by the Appointments Boards of the universities, but only on a limited scale. What was required was a much more extensive enquiry by a trained staff expert in many branches of knowledge and well versed in university affairs, and in close contact with every important walk of life.

Not only should each university carry out a detailed investigation of all the possibilities within its own region, but there should be a pooling of knowledge between the universities. Joint Reports might be issued of the results of their enquiries so that all might know when the demand was greater than the supply, and *vice versa*. This implied co-ordination of effort between the universities, and it was probable that the civic universities, being in close contact with local industries, could make a greater contribution in this respect than the older universities. Such a central co-ordination of effort might well be linked up with the Higher Appointments Branch of the Ministry of Labour, and thus with Government policy. The Government had at its disposal a more extensive knowledge of future requirements than any universities. Hence there was need for close co-operation with the machinery of government.

The next function which an extended University Appointments Board should undertake was to keep a record of their graduates to find out what success or otherwise

[1] This matter was fully discussed at the meeting of the Association in Dundee. See *Advancement of Science*, No. 16, page 311.

they met in their various appointments, and to discover what qualities helped towards success. Such close contact with past students would be helpful not only to the students themselves, but also to the universities which produced them. Past students might provide critical and constructive comments on university courses and make suggestions for their improvement in the light of their experience in the outer world.

Contact with students, closely maintained and supplemented with similar contacts with employers, would provide in the course of a few years a body of information which would be invaluable to the universities and to the nation generally. It would be possible to give real guidance to students at the outset of their careers as to the directions in which there were the most promising openings.

It was an unfortunate fact that many students entered the universities with a narrow degree of specialisation which dictated the course they should take. Boys who would be the scientific experts in 10 years' time were now preparing for the School Certificate Examination. What guidance could be given them as to the future possibilities?

This suggested a further responsibility which devolved upon universities, which stood between the youth in the schools and the wide outer life of the community: they should make available in accessible form all the information available to them on careers for trained university graduates. Such information, wisely used in the schools, would do much to prevent a tragic waste of national talent.

At the close of his remarks Sir John Lennard-Jones said that, if his plea commended itself to the Conference, he would be prepared to submit a resolution in the following terms:

> 'This conference, recognising the great responsibility devolving upon the universities because of their key position in the life of the community, recommends to the Council of the British Association that the University Grants Committee be invited, in collaboration with the universities—
>
> (1) To make extensive factual surveys of the openings for graduates in the national life;
>
> (2) To maintain records of the careers of university graduates and the measure of their success in their professions;
>
> (3) To publish periodic reports of the results of such surveys for the guidance of universities and schools.'

Discussion

In reply to a question by Prof. Irene Manton who asked whether a serious study had been made of the relative percentages of the population attending universities in different countries, and the manner in which they were absorbed into industry and other work, Prof. Blackett said that the relative percentages were known, but there was considerable scope for a study of the distribution of students in Faculties and the relation between the course of study and the employment ultimately obtained by graduates.

Replying to a question by Dr. C. Arscott who asked whether it was the case that the examination standards set by the universities had the effect of causing undue specialisation in the grammar schools, Dr. Eric James said that, in his view, it was a popular fallacy that the universities imposed shackles on school curricula. It was, nevertheless, true that there was great scope for co-operation between universities and schools in arriving at acceptable conclusions on the scope of a general education.

Mr. Ritchie Calder said that the challenge of the Barlow Report was a real one, real in the sense that, unless the intelligence demanded by the Report were produced, the future of the country would be grim: and it seemed obvious that the future depended, above all, on producing sufficient graduates who were adaptable and mobile.

Current estimates of Government expenditure included something like sixty million pounds to be spent on Defence and Supply Research, four million pounds to be spent by the Department of Scientific and Industrial Research, half a million pounds by the Medical Research Council, half a million pounds by the Agricultural Research Council, and a figure of nine million pounds increasing to sixteen million pounds to be spent on the universities, of which a very considerable proportion would be spent on science, because it was in science that the most expensive equipment and development lay. The aggregate was well over the total spent on the whole of education under the Board of Education 10 years ago, and it was clear that, unless the money were spent effectively, the country would not, in fact, pull through.

The problem of middle-class unemployment as a possible deterrent to the effective carrying out of university expansion, seemed almost irrelevant because, unless there were adequate trained intelligence and equipment, there would be universal unemployment and it seemed to be a fact that, unless something of the order of the demands put forward by the Barlow Report were achieved, a policy of full employment could not be implemented.

Mr. Calder said he thought that much greater emphasis should be laid on the regional character of the universities. This meant not that university education should be localised, but that the interest of the public, of the industries of the region, and so on, in their own university, should be stimulated. It had recently been shown that 9 out of 10 of all Scottish science graduates were exported, the bulk of them migrating to the south-east corner of Britain. That was a very serious matter economically for Scotland ; it was also something which might be prevented by co-operation between the universities and industry. Emphasis should be on greater and more intelligent interest both in the university and in the region, and interplay between the two so as to arrive at a corporate understanding of the needs of the area and also of the particular needs of recruitment.

In conclusion, Mr. Calder said that he believed that the biggest contribution that the universities could make was by producing not only the functional citizen, but the civilised citizen who happened to apply his function, and above all the citizen who was highly adaptable.

With reference to the proposed resolution, Prof. R. E. Peierls said he thought it would be exceedingly dangerous to attempt, on the basis of an estimate of the probable requirements of graduates in general and particular subjects, to adjust the number of students or graduates admitted or trained. When tooling up for production, manufacturers found it very difficult to know what the demand would be for their products when they were ready to supply them. Sometimes their estimates were wrong and their products had to be scrapped, but the same risks could not be taken with graduates. He did not oppose the proposal by Sir John Lennard-Jones, that data should be collected but said he felt strongly that the greatest caution should be observed in the use to which such information was put.

He thought that the answer to this question lay in trying to develop, and he thought it was the task of the universities to develop, a change in attitude, namely that, by getting a particular professional training a man did not acquire the right to be employed in a particular professional job. The position in Britain was often compared with that in America, where the proportion of graduates was very much higher. This was made possible in America by the fact that the attitude was different. Many people went through college, and very many even to the equivalent of our B.Sc. Degree, who afterwards took posts for which such a training or Degree was not strictly designed. If one found in the United States a graduate who happened to have a job as a wages clerk in an office he did not say, as he would do here, ' I am a very unhappy man, my career has gone wrong ; I started by getting a Degree and now I am only a wages clerk.' His attitude would be rather ' I am an extremely lucky man because I am only a wages clerk, yet I have had the benefit of a university education.'

University education should be a means of making life richer through experience and through contact with things which would otherwise be missed. It should put one in a position to talk to people to whom one would not otherwise be able to talk ; to listen to things and to read things which would otherwise not be open to one. If a man were fortunate enough to find a job in which he could actually use in his training so much the better, but it was dangerous to educate people with the idea that they were trained to do this or that particular job, and that unless they could go out and do it, they were misplaced.

Speaking on behalf of the National Union of Students, Mr. Tony Simmons said that the opportunity given for a student to speak in this discussion was greatly appreciated for, in considering the selection and recruitment of students and their subsequent maintenance and training inside the universities, a knowledge of the direct experience of the students was of value.

Over the past two years students had been compelled to pay considerable attention to the problems associated with expansion of the universities. They knew what it meant to be overcrowded in libraries, hostels and rooms. They were acutely aware of shortages of teaching staff, and in many places had attempted their own temporary solution by organising seminars and classes taken by postgraduates. The costs of higher education had been increased and were becoming prohibitive, maintenance grants raised many great difficulties, and the Further Education and Training Scheme, affecting roughly 30,000 ex-servicemen and women, was a continual source of concern. Then there were problems of student health and housing. The N.U.S. had a wealth of material concerning the life and conditions of students at present in the university when it came to consider the general problem of the recruitment and selection of students in this period of expansion.

The N.U.S. had also considered the position of those who had been able to get into the universities in spite of personal ability and qualifications. The Barlow Report said that ' only about one in five of the boys and girls who have intelligence equal to that of

the best half of the university students, actually reach the universities,' and, in the opinion of the N.U.S., this statement pointed to a state of affairs in the field of Britain's educational system which was both morally wrong and socially dangerous.

In analysing those various problems the N.U.S. had two guiding principles in mind. The first was that, if the system of Higher Education was to be expanded at the required rate, there must be an adequate number of students of high quality to fill the universities. The second was that, during this period of expansion the intention should be to develop a system of free and equal higher educational opportunity open to all on the basis of merit alone.

The conclusions of the N.U.S. on these questions were epitomised in a leaflet published at the end of 1946 entitled ' Where are the Ghost Students ? ' It stated that the ghost student was kept out of the universities, and the actual student was seriously hampered, by factors which would disappear if the following four points of policy were put into effect as part of the general plan for expanding higher education :—(1) Abolition of all fees. (2) Maintenance grants for all students. (3) Co-ordinated basic rates for all grants, regardless of Local Education Authority area. (4) A minimum entrance standard.

Mr. Simmons developed the students' argument in favour of each of these recommendations, giving particular emphasis to the need for adequate maintenance grants. Excluding ex-service entrants to universities, only 4,000 out of an annual intake of over 20,000 students received financial aid from the State, either directly or through Local Education Authorities. He concluded by suggesting that, when ex-service students had passed through the universities there should be another scheme, similar to the Further Education and Training Scheme, open to all students, recognising the essential character of the work they had to perform and remunerating them accordingly.

Mr. E. M. Hutchinson (Secretary of the National Foundation for Adult Education), referred to adult education and continuing professional education as an important factor in the relationship of the university to the community. He said that the Local Education Authorities had been asked by the Ministry of Education to prepare development plans for further education. One of the issues stressed, under the heading of ' Learning for leisure,' was the question of co-operation between the agencies that promoted further education in the adult community namely, the Universities, the Local Education Authorities and certain voluntary agencies. There was a need for the application of research to this problem of catering for a wider audience than could ever be reached within the walls of the university, however much extended grants and accommodation might increase the actual intake of the university. There was a danger of increasing the gap between the specialist range of knowledge in the universities and the employment of it on the part of the community at large. This was an aspect of the relation of the university to the community that should take a prominent part in current thinking. It was an important issue at a moment when certain administrative processes had been brought to bear on the whole field of adult education. Once a particular form of development plan was adopted within the field of public education, it would not be particularly easy to alter the lines of that plan. It was important, therefore, that the co-operation asked for by the Ministry of Education should be conceived at the university end as a vital instrument for developing the relationship between the university and the community.

Another speaker on adult education (Dr. Harlesden) referred to the fact that only a very small proportion of adult education programmes dealt with science, and said that organisers of such programmes would welcome the co-operation of university scientists in developing the latent interest of the community in scientific subjects.

Miss Fullblood said that the difference between the salaries paid to graduate and non-graduate teachers provided insufficient incentive to maintain the flow of teachers with university degrees. For a number of years the loyalty of existing graduate staff would prevent the position from becoming serious, but if the reward of graduation were not increased, the best people would naturally seek more profitable fields for their labours, with the result that future students of the universities would be taught by men and women of second rate ability. Miss Fullblood also stressed the difficulty of retaining children at school between the ages of 16 and 18, and suggested that much waste of talent could be avoided at that stage by maintenance grants.

With regard to wastage of talent, Mr. Brian Simon said that his experience as a teacher of children aged 11 in a modern secondary school suggested that a proportion of gifted children became casualties at that age because they did not succeed in intelligence tests. Their failure to pass such tests was due partly to the nature of the tests, partly to the home environment of the children and partly to the quality of their education which did not develop their

inherent ability. He advocated revision of the tests and, more drastically, a recasting of the education system.

In conclusion, Sir Henry Dale said that the discussion had ranged widely to allow attention to be given to the intake and preparation for university life. Sir John Lennard-Jones, however, had read a motion which took account of the output of universities and called for a fact-finding inquiry with regard to the results of university education and of scientific education in the university and he thought this was an important matter on which it should be possible for the Conference to reach agreement. He supported the resolution because the only possible scientific attitude was to call for facts before deciding what to do. He thought that Prof. Peierls was right to underline Sir John's intention that the facts should be dealt with intelligently when they were obtained. The function of the universities was essentially a cultural function, and the proper business of the university in regard to science as well as other studies was to provide the people of the country with a wide content for their intellectual life, and he hoped that an inquiry would find out, for example, what proportion of the people with a scientific training were going into the Civil Service or Parliament without following a particular profession or particular branch of the scientific professions for which their graduation would seem to have specially qualified them.

The resolution moved by Sir John Lennard-Jones, was carried unanimously.

Second Session

RESEARCH AND ORGANISATION

CHAIRMAN: SIR HENRY DALE, O.M., G.B.E., F.R.S.

In opening the second session, Sir Henry Dale said that the first session had dealt, in the main, with universities as the organs of higher teaching, with the intake of students and the output of students, and with the contribution thus made to the general interests of the community. The discussion would now deal with universities as centres of research, particularly of research in the natural sciences, on the organisation of such researches, and the sources of their financial support.

It was particularly appropriate at this juncture to have a discussion on this matter of research in the universities, to consider what it was and what it ought to be, and what was the particular research function of the universities. It was obvious that the universities were just emerging from wholly abnormal conditions imposed by the war, when the activities of almost every science department were very largely given over to work directly or indirectly undertaken for the Government, on prescribed and, for the most part, secret projects. The universities were emerging from that obligation but finding themselves, at the same time, as several speakers had pointed out in the first session, already dependent for 75 per cent. of their income on money from the public purse, to be applied now to peace-time activities. There were obvious dangers that war experience, the assumptions and habits of mind engendered by the abnormal occupations of war, might too easily be carried over into the conditions of peace. The Government organisations which had supplied the funds, together with the nation's industries, had experienced for the first time during the war the full possibilities of prescribed and directed researches, carried out for them in the Science Departments of the universities. It seemed desirable, and even urgent now, to consider very carefully what was the proper normal function of research in the universities.

Sir Henry said he thought there would probably not be any great difficulty in agreeing that the particular function of the universities was that of independent research and he chose the term ' independent ' rather than ' fundamental ' research, because the latter involved other ideas. The distinction between fundamental and applied research was, on the whole, a more difficult one to draw, and one concerning the validity of which there might be some difference of opinion. If, however, distinction were drawn between fundamental and applied research, and if the question were asked which should be particularly the function of the universities, again there would probably be no difference of opinion. The advancement of fundamental science would be regarded as the particular, though not the exclusive, task of research in the universities. Research in the sciences ancillary to agriculture and to medicine tended to be applied research, according to the usual definition, rather than fundamental ; but nobody would desire to exclude them for that reason from the activities of the universities. The real distinction was between free or independent researches, undertaken with no obligation to keep to a definite course or to limit activities to the solution of a pre-ordained problem, and prescribed researches, undertaken to solve a prescribed and usually a practical problem. The special function of the universities

was free research rather than prescribed research.

The universities should, then, have the special function of encouraging investigations having no obvious relation to applications which could be foreseen, though, according to all experience, such researches very often led to practical applications more important than those which come from researches undertaken with a prescribed and practical object.

The object, then, of the universities was to promote researches undertaken with no practical objective but to widen the boundaries of knowledge and to discover truth for its own interest and for its cultural value. That should not—though the point might be one for discussion—exclude even contract researches commissioned by some outside body, if freedom were allowed, and if the offer of financial support for an attack on a named problem did not divert the academic worker from the natural line of his own ideas. One condition of academic freedom, however, should be put right in the foreground ; that was that there should be an absolute embargo on secrecy. Sir Henry mentioned that he had recently made that suggestion in the course of a lecture in the United States of America, and had met with a surprising unanimity of approval from scientific colleagues, not only in academic circles, but in the centres of industrial scientific research as well. In particular, the Director of one of the most important research organisations supported by industry in the United States said, ' I think that you are absolutely right. We ourselves support, and desire to support in increasing measure, research work of a perfectly free kind in the universities. We like to encourage work in the universities on fundamental problems the solution of which will sooner or later be of interest to us ; but, if the investigation is one on the results of which we want to impose any kind of secrecy, we would rather keep that out of the universities and deal with it in our own research organisation.'

The wider question, as to how far secrecy might be anywhere desirable, was outside the scope of this Conference, but as regards the universities, he considered this principle to be so important that he proposed to make a suggestion in the form of a resolution as follows :—

> ' That this Conference recommends to the Council of the British Association that they should make representations to the competent authorities of all universities in the British Empire urging that no contract for research should normally be accepted by the Scientific Departments of any of those universities, if its terms include any restriction on freedom of publication.'

Dealing with the cultural function of science in the universities Sir Henry said: Speaking for the British Association for the Advancement of Science, and its Division for the Social and International Relations of Science, I suggest that the cultural value of science is a matter on which we might well insist more strongly than we do. As scientists we are rather apt to allow ourselves to be forced into a semi-apologetic attitude, admitting that science is not all that is needed for a wide culture, but concerned chiefly to protest that all scientists are not without culture in those divisions of learning which have rather arrogated to themselves the title of ' the humanities.' I was glad to note that the Master of the Rolls, himself a distinguished classical scholar, recently addressing the Classical Association and insisting on the educational importance of ' the humanities,' went almost out of his way to claim science as a proper part of the humanities. This is a recognition which we ought greatly to welcome. In my experience, scientists have not usually the habit of boasting that they know nothing about the arts ; it is our literary colleagues who are inclined to boast that they know nothing at all about science. We should insist that science is a proper item of a liberal education, and that a general knowledge of the principles of natural science is an essential part of human culture in a world which is rapidly moving into the scientific era of its civilisation. If that conception of science in the universities is to be accepted and maintained, I think that we can claim that it is one of the finest of moral disciplines. Better than any other, indeed, it can hold up to its students and practitioners the ideal of a patient devotion to the pursuit of objective truth, undeflected by personal or political motives, fearing nothing but prejudice and preconception, accepting and reporting Nature's answers with an unflinching fidelity. That seems to me to be an important factor in the moral culture of mankind. We ought to maintain that it should be the function of the universities to hold aloft the ideal of the search for truth, in all its aspects and by all methods, including those of experimental science, and to provide, each in its own area, a focus and a radiating centre for such humane ideals.

Sir Henry referred to the provisional syllabus of the conference in which something was said about cross-fertilisation and contact between industrial and academic research. He said he would like to add, also, between research in the Government laboratories and

academic research. He thought that there was a very good case for fostering the widest possible interchange of research workers. While some academic workers did their best work under conditions of unbroken and cloistered seclusion—and nobody would wish to deprive such men of it—there were others whose freshness of ideas would gain by transportation, perhaps for a short period of years, to research bearing on some practical applications of science. On the other hand, there were many workers in the research departments of the Government and of industry who could be similarly refreshed by a spell of work in the freer air of academic research. For workers in Government laboratories that had recently become much more easily practicable, through the wise adoption of the new terms of engagement, and of pension rights in particular, in the scientific Civil Service.

Dealing with the sinews of peace, the production of the financial resources required by the universities for their peace-time research programmes, Sir Henry said that modern research equipment involved costs of an altogether new order, and the universities would not be able now, to any serious extent, to depend on private generosity and private endowment for the support of their researches. They would have to get support from the Government or from industry, and the question of the basis of distribution of the money made available from the public purse was one which needed discussion. It was becoming obvious that all universities could not be supplied with all the equipment which all the scientific departments would need. There would have to be some scheme of allocation of the available money. Could this be undertaken by a co-ordination of their requirements in advance by the universities themselves? Could they discuss the application which they were going to present to the University Grants Committee, and arrive at some suggested basis of allotment beforehand? Or would they prefer to leave it to the Government authority? If the latter, it was obvious that the Government authority would need to be assisted by a much larger body of special scientific advice than it had hitherto had at its disposal. This was a question which might usefully be discussed.

Prof. M. Polanyi, F.R.S.

PROF. POLANYI opened his contribution to the discussion with a reference to the fact that, with 75 per cent. of their income supplied by the Government, the universities would in future be regarded rightly as a national responsibility. It was necessary to clarify the principles according to which the Government could allocate funds for academic purposes and ensure that they were used with efficiency and economy. The following are extracts from his communication:

The drive towards the expansion of universities, and in particular for the training of more scientists, is prompted largely by the desire to exploit the intellectual resources of the nation more effectively for purposes of material warfare. It also aims at giving equal educational opportunities to all classes.

If we want to expand higher learning we must be resolved to maintain this higher learning. This means that the universities must be sustained as well-springs of discovery, for an advanced scientific education can only be imparted by teachers who are themselves actively engaged in discovery. Scientists who are not engaged in discovery, and who are not called upon to renew their knowledge continuously, may be often ten years out of date, and their teaching perhaps even twenty years out of date. They will inspire no serious thoughts and can answer no difficult questions. They convey a rigid and final picture of science which is entirely misleading. In fact their teaching is usually as dull and sterile as it is obsolete.

To provide for higher learning in universities, therefore, all teaching of science, and all research, must be under the control of persons successfully pursuing discovery: they must supervise the activities of all personnel who have not yet acquired maturity as discoverers or happen to lack the ability for discovery. Each senior scientist can look after only a limited number of junior staff, research students and undergraduates. Ten junior staff, twenty research students and a hundred undergraduates are as many as most professors can expect to supervise effectively; give anyone three times that number and he will cease to be an active scientist.

A university system must rely for all its essential functions on a staff of creatively-minded professors and younger men and women in training for professorships. But this still leaves open the important question to what extent, if at all, specific tasks of teaching or research should be allotted to the persons occupying these positions. This is a fundamental issue.

There are plenty of examples of creative work done by order. Why should not the work of academic discovery be guided likewise by the interests of national welfare, since the nation is to finance the process of academic discovery? The answer is that there is a profound difference between academic discovery and the creative activities of the portrait painter, the architect, the

judge, the doctor and the practical scientist. The difference is that in academic research the choice of the subject is in itself a creative function of a high order. To find a field where discovery lies hidden, and yet within reach of a possible effort—an effort which the potential discovery will repay—to guess all this is the most difficult part of discovery.

Moreover, there is a quality which distinguishes the process of academic discovery from all the other creative activities of man. It is expressed by a single adjective, the word: systematic. The systematic coherence of science makes scientists depend on each other and is indeed the reason why they form academic communities ; even though the originality of their creative efforts, which is absolutely essential to their success, makes it necessary that in this community each should exercise complete independence in the choice of his task. A brief examination of such communities leads to the proper principles of academic policy.

In spite of their radical individualism, the members of academic communities derive great benefit from each other's company. It is a commonplace of scientific life that to live within a great university makes it much easier to do research. Many a young scientist who had done well in a junior position at a distinguished university sinks into inaction and oblivion on his appointment to a chair in some less advanced institution, where he has no active scientists as his colleagues. It is the inside view of science which scientists gain by living together and meeting frequently to discuss common interests. To which must be added, as perhaps even more important, the common upholding of certain essential values and motives ; the love of science and the desire to achieve discovery. For these wither only too quickly away in an atmosphere that is not sympathetic to them.

That is why academic communities are essential for the pursuit of systematic discovery, and why it is uneconomical, if not altogether useless, to foster such discovery in any other place. When industrial laboratories, which have their own important practical purposes to pursue, try to include some part of pure science in their programme, they are likely to be wasting their efforts. Unless the investigation is clearly required to fill in the background of their practical work and is also clearly of insufficient scientific interest to be pursued at a university for its own sake, industry should leave it alone.

On the other hand, the universities should not take on problems of practical life, which arise in fields outside their own range of experience. They cannot be real masters of these problems, and in dealing with them they can use their technical skill only while their powers of higher judgment are left unemployed.

If at any period of history, it should become necessary to use academic scientists for other than academic purposes, then they should be allowed to leave their university and join the organisation serving these extraneous aims. That proved to be the rational way in the last war and the lesson should not be lost.

This policy should not exclude occasional consultations with industry, which can indeed be most useful. So long as the natural distinctness of academic activities is recognised and safeguarded, there is much to be gained by increasing the range of their outside contacts, both in the interest of the universities and for the sake of the outside world. Outside control paralyses a creative process, but outside impulses may stimulate it.

The nature of the task of organising universities, particularly on the scientific side, is thus becoming clear. It consists in giving freedom and scope to a process of systematic discovery. The academic authorities must foster the growth of academic thought on the lines of its own inherent logic—watching the advent of new discoveries and preparing accommodation for their further pursuit, in whatever direction that pursuit may lead.

The growing-points of science are marked by the rise of men who make distinguished discoveries at those points. The obsolete or dormant parts of science are marked by the fact that they do not produce any distinguished scientists. The authorities must recognise that there is no other criterion by which they could distinguish between what is alive and what is dead in science.

Once this basic fact is firmly grasped, the academic authorities should have no hesitation in formulating the chief elements of their policy. They will undertake to find senior appointments at universities for all scientific discoverers above a certain level of distinction, irrespective of their field of enquiry. They will not appoint to a professorship anyone below this standard, however urgent the filling of the vacancy may appear on the grounds of prevailing custom. Such a policy will occasionally lead to the overcrowding of some departments which produce a rich crop of distinguished young scientists in their particular branch of research. Other departments will be left with vacant chairs indefinitely. The crowded departments should be expanded at the expense of those which are inactive. In this way the correct balance of the respective branches of science will be established in accordance with the progress of science.

A policy of filling each vacancy by the most distinguished scientist who is available, regardless of his special field of enquiry, has been practised deliberately by most universities and we may rightly ascribe it to the constant renewal and strength of the academic system throughout its history. The exercise of a more centralised control could not only be guided by the same principles, but could be even more effective in applying them. It is always difficult to make drastic changes in favour of one department or field of enquiry by a local decision within a university, and this is more easily done from a distance. In a sense we can see this happening already to-day through the large special grants given by various central funds to distinguished scientists, which they use to improve the relative position of their subject in their university. By subsidising on an ample scale the work of eminent scientists, the Rockefeller Foundation has done, and is doing, a great deal on these lines to readjust the balance of subjects in universities throughout the world.

An effective way of carrying out the expansion of universities would be for the central authorities to give large grants to a number of young and active leading scientists for the expansion of research and teaching, both in their own field and in fields neighbouring those in which they are interested. They should be given a single large sum for the cost of new buildings to be contsructed to their own plan, and promised support for new chairs and other posts which they might suggest within their zone of interest. By such endowments the authorities would be sure to obtain excellent scientific value for their money.

So long as the central academic authorities recognise their function in giving opportunities to good scientists to work on the lines of their own choice, the authorities will be using their money wisely and economically. Such a principle, no doubt, needs qualification in many respects, particularly on account of the requirements for the training of candidates for various professions. On the whole, a panel of good scientists could be relied upon to devise the best training for the professions for which they prepare, after consultation with the representatives of these professions. Yet the central authorities may have occasion to intervene in order to safeguard some particular educational interest. They may legitimately intervene also to give larger scope to research in certain fields of engineering or other branches of scientific technology which are interesting primarily on account of their practical applicability. They might also wish to call attention to various fields of research which appear to be flourishing abroad and yet are missing at home. So long as the academic authorities uphold the broad principle that their task is to supply individual creative minds with the opportunities to do the work of their own choice, they will not go far wrong when making allowances for other secondary points of view. On the other hand, on such principles it would be impossible for them to agree with the Committee of Vice-Chancellors that it is their function ' to secure that as a whole the universities are meeting the whole range of national need for higher teaching and research.' They would realise that the requirements of science ' as a whole ' are inscrutable or in other words that ' the need for research as a whole ' is—to our human intelligence—represented simply by the aggregated needs of individual discoverers to be allowed to do what they feel inspired to do. Just as the purpose of a team of chess players ' as a whole ' is but the aggregate of their individual objects to defeat their several opponents.

Unless society appreciates science for its own sake, it will not continue for long to cultivate genuine scientific research. Ultimately universities must depend for their existence on the recognition of cultural obligations by the nation. It is the duty of academic scholars, whose task is to uphold the values of knowledge, to demand of society that it should recognise its obligations to cultivate knowledge.

In conclusion, Prof. Polanyi said that it had been urged that academic activities should be expanded by raising the salaries of scholars to align them with those of alternative professions. He believed that academic scholars should always be paid less than they could earn elsewhere. Thus only could they keep their profession free from those who would abuse the liberty which they must have for the effective pursuit of their calling. While a businessman's standing was properly measured by the money he earned, a scholar's should be determined by the money he refused to earn. He hoped that this might be the spirit of the coming phase of expanded academic activities. Otherwise the expansion of universities might become, instead, the destruction of universities.

Prof. J. D. Bernal, F.R.S.

PROF. BERNAL said he thought that the development of research in the universities could only be achieved if there were live schools of research under people actively engaged in the advancement of new knowledge and that the present division of subjects in universities acted as a considerable check to that kind of development. Except on minor points which need not be stressed, he

was in full agreement with a great deal of what Prof. Polanyi had said.

The essential point to be kept in mind was the place of research in the universities in relation to the needs of the community and to research in other places. Beginning with the university there would probably be general agreement on its objects, as set down very clearly by Jose Ortega Y Gasset in his book *Mission of the Universities*. First and foremost, there was the transmission of culture, then training for the professions, and finally the increase of knowledge. Those three objectives were absolutely inseparable ; any organisation that was not increasing knowledge was not fit to transmit culture, and *vice versa* : and the central task must not be forgotten, the bread-and-butter objective of the university teacher—to train in a general way the people who went through the universities for the jobs that they would have to do afterwards.

In the university the function of increasing knowledge was research, and it could be used to increase knowledge in several radically different ways. Experience of war research had helped to clarify ideas as to the different kinds of research there were and one of the distinctions which were then stressed was that between what used to be called objective research and subjective research. Perhaps the less confusing names convergent research and divergent research would render their meaning as well.

By convergent (objective) research was meant research tending towards a specific determinable object, such as how to sink submarines, a research which might involve any number of techniques or any combination of techniques, but in which the object was always kept in view and only materials and discipline were brought in which would serve that object.

The other kind of research, divergent (subjective) research, arose when there was a field of knowledge which had a certain intrinsic coherence from which a number of divergent applications were likely to arise. For instance, during the war there was a committee on mud. The interest was not in mud as an object, but as a subject common to a large number of military problems, whether it was mud to be got through or mud to be built upon. In one way or another, essential knowledge of the subject had to be furthered in order to solve a whole divergent set of problems instead of collecting a mass of knowledge centred on one problem, as in convergent research.

These were not merely abstract definitions. The conceptions of convergent and divergent research were bases for practical action, and the centres around which groups of research workers were formed. Nor did the contradiction between the convergent and divergent approach lead to unnecessary confusion, for each convergent line drew from a number of divergent sources, and each divergent research fed a number of convergent sources, forming together a network of research problems. The general tendency of this network was to link the fields of theory with fields of practice, and so the convergent research tended to be more applied and the divergent to the more fundamental. But this was only a relative distinction, for examples of both could be found in all ranges of the purest science to the most practical applications.

In developing this argument Prof. Bernal said : There are plenty of examples of convergent and divergent research inside the field of fundamental research itself. One might instance the problem of the determination of protein structure. This is a definite problem. For every protein there is a characteristic arrangement of atoms ; but the end cannot be envisaged from the start. There is not just one way of reaching that end. The problem can be approached simultaneously through a number of radically different scientific disciplines ranging from the physical discipline of the electron microscope and X-rays through chemical methods to the purely biological methods of immunology and genetics. We are beginning to appreciate that the rate of our advance towards the solution will depend very largely on the degree to which these different methods are co-ordinated, the degree, that is, to which the whole is treated as one convergent piece of research.

On the other hand equally in the field of fundamental science we have such a subject as electronics, where knowledge of the behaviour of electrons in complicated fields of oscillatory systems furnishes different possibilities for interpretation of a large number of problems in all their ranges of science from physics to sociology. Generalisation of electrons is therefore a typical divergent research field. It should therefore be clear that the function of research in the universities need not be and should not be confined to systematic and abstract study of natural forces or phenomena : that this should be seen in relation to the full complexity of the whole scientific effort including its technical aspects, and that the method of science even in universities can draw as much from the practice and theory of governmental and industrial research as they can give to them. That is not to say, however, that all research should necessarily be undertaken in universities. From their character both as teaching institutions and

centres of culture there will arise a certain selection of the range of subjects that are most appropriate. Determination of this range is a problem in its own right.

As regards planning of the research field, Prof. Bernal suggested that it was possible to argue, as people had argued for many years, about what research should be done in the universities and what should not, but the time had come to undertake research on research to find out, by actual examination of what people were doing now, and of the trends of what they were doing, what research was most suitable to be done in universities, what in Government departments, and what in industry. Only after this had been done would it be possible, in his view, to begin to reach satisfactory long range solutions. There were a large number of researches actually going on in universities up and down the country, researches centred round the particular abilities of a limited number of men, so that, in planning the future, particular local traditions and individual factors would have to be taken into account. The field of fundamental science, however, large as it was, was not so large that it could not be comprehensive, and a moderately rational scheme of research could be built round existing trends in such a way as to add to their speed and effectiveness.

There were dangers in blindly increasing the volume of research in universities and it was because of these dangers that careful consideration was necessary. Prof. Bernal did not think, with Prof. Polanyi, that it could be left entirely to the spontaneous action of a group of academic scholars detached from ordinary life: but it was possible that these same scholars, given an understanding of what the problems were, a full system of interchange of information, and some degree of clerical assistance, could do far more than was being done now to increase both the productive capacity of the country and the advance of science. He thought, on the whole, that the divergent type of research, working out freely all the implications of certain bases of knowledge, was the more appropriate sphere for university research activities, and the initiative and consequently the control of this work should be left entirely in the hands of the scientists themselves: but it should be open to outside authorities to suggest many of the subjects for such researches, to hand them out, so to speak, to anyone who was interested enough to undertake them for their own sake and competent in the opinion of his peers to carry them out successfully.

Prof. Bernal said he thought that scientific workers in universities could be trusted to take contracts for definite pieces of research, convergent as well as divergent, and get an advantage out of them in the universities, and he conceived a new kind of university research worker and research director who would be able to integrate such research into the other functions of the university. It should be realised that the science of to-day, and more so the science of to-morrow, involved many more factors than were considered in the past. In dealing with so-called practical problems it was not a question of the innocent scientist getting involved in a field he knew nothing about, but of the ignorant scientist applying his scientific method to just those parts of the field that were not considered scientific before, namely to the economic, social, and other aspects of the field.

Speaking on choice of subject for research Prof. Bernal said he agreed that this should, in the last resort be an individual responsibility, but he added that individual choice could only be made effectively if those who had to make it appreciated clearly what they were choosing. A weakness of the position of the individual scientist in the past was not an intrinsic one but rather depended on the fact that he never had the field of relevance of his work properly represented to him, and had to make choice without adequate knowledge, thus missing discoveries which had to be left until either the force of accumulated evidence or the particular ability of a widely read and far-sighted scientist produced them. Only by providing adequate knowledge, which meant a better information service and better staff work in science, could the individual scientist be given an opportunity of making a much more rational and fruitful choice. Once a worker was fully informed he was most likely to be successful if the field he worked in was one of his own choice.

Many older scientists seemed to fear the organisation of science for making available information and exchange of activity. Far from hindering the freedom of science, this was the only way in which that freedom could be effected. In the degree to which the knowledge sought in scientific research was fundamental it was also universal. There was no reason why it should be pursued in one place rather than another. This was the justification for making it the responsibility of universities that claimed to deal with all knowledge and with all men without boundary of creed, race or nation; but, such fundamental knowledge does not exist separately: it was alive and fruitful in proportion to its continual contact with more practically realisable research. Every university, therefore, must, apart from its

universal character, acquire a certain national and regional character in relation to its research.

Industrial regionalisation was based largely on local resources and local history, on the position of coal mining or ports. It was natural enough that wool research should centre in Leeds and cotton research in Manchester, but the regional work of universities should mean something much more than this. Just because there were no regional administrative units, the universities had special responsibility to create such units in the field of research and culture for themselves. One of the most valuable contributions of the universities of the Middle Ages was that they provided the focus of general intellectual culture in the regions which they served. This function could not be revived without bringing in research, for a university pontifically teaching a static culture would never be of any use to its region.

The university must go out into the region to discover what the problems of the region were. The social surveys begun in Manchester and in other parts of England were a fine beginning: but they were only a beginning. The university should become a focus for studying and dealing with the requirements of the region as already known, and with others that could be determined by further surveys. The university should increase its contacts with industry on both sides, employers and trade unions, and in that way collect problems. This would have the effects that: the functions of the university would be better understood and consequently better supported; the general spirit of culture would be brought home in an effective way to the people around the university; and the intellectual life in the university itself would benefit by contacts which would suggest new problems and lead to a continual widening of understanding and experience of the world. It was characteristic of the modern world that it was approaching a state where more and more of the nature that scientists were required to investigate was organised human nature and social nature, for it was the actions of society and the work of the people from day to day which were the basis for the knowledge that it was wished to refine and apply in the universities. That could best be done if the universities went out to the people. Practically everybody in industry, workers and management alike, as well as those in agricultural and domestic work, could be made to become scientists, not considering science as something apart from their lives, but considering themselves as part of the scientific world.

In the report after every army exercise and operation, there was always left a space for lessons learnt. In so far as lessons could be learnt from activity, that activity became part of a scientific experiment. In the same way a report on lessons learnt from every industrial enterprise or engineering construction might be demanded. The organisation of all industry and enterprise as part of science was clearly not something that could be done centrally: it must depend largely on voluntary effort organised locally and regionally, but the universities could play a large part in helping this movement forward and giving a responsible scientific form.

In conclusion, Prof. Bernal urged on his listeners the need for a determination to undertake the more immediate task of explaining their own research and increasing its scope on a regional basis, and of increasing the integration between these three functions of the university: the transmission of culture, the training of the future professionals, and the furthering of human knowledge.

Discussion

Dr. C. H. Desch, F.R.S., said he regarded the relation between the universities and industry as one of the most important subjects to be considered at this Conference. He spoke with particular reference to the steel industry in which there had been a great change in the type of demand that was made on the universities. Not so long ago this industry had asked for people trained in physics, chemistry or engineering so that they might work in testing laboratories. Methods of testing had become so standardised that the work could now be done by boys from secondary schools. On the other hand, there had been considerable development of research and great changes within the works themselves. Not long ago, managers of steel melting shops and rolling mills were promoted foremen. It was becoming more and more usual for such men to be university graduates and there was a great demand for university men who had had a theoretical training in the fundamentals of science, not merely as specialists, but with a wide scientific outlook so that they could grasp the opportunity of using new scientific methods and apply them to the particular industries with which they were concerned.

With regard to secrecy in research, it could be claimed that such a thing did not exist in the steel industry. It did at one time but where it was now necessary to protect a process it was covered by patents.

Research Associations occupied an important place at the present time. A great deal of the research in the larger industries

is now done co-operatively through the Research Associations, sometimes through central laboratories, but largely by the work being assigned to different universities. The universities were asked to undertake a particular kind of research, and the Research Association provided the necessary funds to employ postgraduate students on that kind of work. In most cases that policy was applied in a liberal way, and there was no secrecy. It was understood that the work was confidential until published, but there was an agreement that the work should ultimately be published, and in that case the student got full credit for his work. This arrangement had been found valuable by many universities as it often enabled them to provide expensive apparatus and gave interesting work for a number of senior students with whom the professor in charge was closely associated. There was a great future for the universities in the development of this form of co-operation with industry.

Dr. E. H. Kellerman described some of the views on university policy which were held by the Association of Scientific Workers. In so far as they had a bearing on research, those views implied three main principles, viz. : freedom of publication, ample funds for projects and adequate remuneration of individual research workers. As regards subjects for research, it was thought that more attention should be paid to the social sciences. Dr. Kellerman referred to a number of administratvie adjustments and organisational developments which were advocated. In the domestic sphere they included more representation of junior staff and even of students, on administrative bodies. For the universities as a whole it was suggested that there was a need for an effective body charged with the formulation and general oversight of policy. Neither the University Grants Committee nor the Committee of Vice-Chancellors appeared to be so constituted as to be able to perform this function. Possible alternatives were an enlarged Association of University Teachers or a new Academic Council.

In a general discussion which followed, Prof. T. H. Pear said that two of the activities of a university might be compared with a lighthouse and a casserole. The second function was scarcely neglected in scientific departments. Delicate new flavours of scientific knowledge were lovingly distilled but allowed to enrich only the circle in which they originated. The public relations of science were not good.

Scientists lived in a community and their relations and duties to it could no longer be ignored. It could hardly be believed that there were many scientists who had no idea of the immediate use to which their discoveries might be put. To the social psychologist it seemed a scientists' moral duty to think what would happen as a result of his work and to whom it would happen, and, moreover, to see that beneficial discoveries percolated through, or flashed forth, to as many people as possible. To the man in the street science was important because its results affected his life at every point. Some of the discoveries which the public heard about made them slightly uncomfortable : they should be told that scientists were not always up to mischievous tricks : the beneficent discoveries should be stressed and the public should be told, moreover, that, when for example discoveries were made which saved lives, the scientists knew how it was done.

It was equally important that not only the general public, but most physical and biological scientists also, should understand something of the aims and methods of the social sciences. It might be said that most people when thinking of science tended to worship the elegant exact methods of the physical sciences. So far as they could, social scientists employed exact methods and were inspired by their ideals : and it should not be overlooked that social scientists were also inventing techniques which might affect the applications of the physical sciences.

At the close of the Conference the resolution proposed by Sir Henry Dale was passed unanimously for consideration by the Council of the Association.

Postscript.—The two resolutions passed by the Conference were subsequently approved by the Council of the Association.

Resolution : This Conference, recognising the great responsibility devolving upon the universities because of their key position in the life of the Community, recommends to the Council of the British Association that the University Grants Committee be invited, in collaboration with the universities—

(i) to make extensive factual surveys of the openings for graduates in the national life,

(ii) to maintain records of the careers of university graduates and the measure of their success in their professions,

(iii) to publish periodic reports of the result of such surveys for the guidance of universities and schools.

Report.—By the end of August it was reported to the Council that the Ministry of Labour were making a survey which would provide information regarding openings for graduates and that the University Grants

Committee were compiling records of the output of graduates in particular subjects: also that the U.G.C. were considering what further steps could usefully be taken to obtain better records of the careers of graduates.

Resolution: This Conference recommends to the Council of the British Association that they should make representations to the competent authorities of all universities of the British Empire urging that no contract for research should normally be accepted by the Scientific Departments of any of these universities if its terms include any restriction on freedom of publication.

Report.—This resolution was communicated to the governing bodies of 85 university centres in the Commonwealth. Replies are still being received and the comments have been wholly favourable.

CHEMICAL RESOURCES AND INDUSTRIES OF SCOTLAND [1]

Some principles of raw material development

In discussing the general principles of raw material development Mr. Robert H. S. Robertson said that raw materials may be irreplaceable, non-cyclic, wasting assets or they may be replaceable, cyclic, income-resources. The wasting assets include metallic ores, phosphates, salt, sands, clays, and minerals, as well as the organic materials, coal, oil and peat. The replaceable resources are crops, marine and terrestrial animal life, seaweeds, and trees, and may for convenience be allowed to include water and air. Although replaceable, these resources are not all limitless in quantity, and some make demands upon the non-cyclic resources for their continuance, *e.g.*, mineral fertilisers for crops.

General principles. Man is slowly becoming aware of the evil effects of his devastation (2) of resources, both human and natural, and is beginning to formulate and even sometimes to practice more moral principles of resource development, taking a longer view than the previous generation of colonial exploiters. The trends of thought to-day are towards unified resource development based on the unity of man and nature, regional long-term development, the principle of equitable participation by all nations in national surpluses as enunciated in the Atlantic Charter, and the 'Hot Springs' exhortation to make the best use of each nation's or region's resources, exporting only natural surpluses and, whenever possible, manufactured goods.

(i) *Multiple utilisation.* The aim should be to find the greatest number of different uses for a product, so that the discontinuance of one use does not jeopardise the industry. In the past many industries have failed because they relied upon a single major application. For centuries the main use of fuller's earth was for the fulling of wool, for which purpose it was slowly ousted by soap. It is only since a number of uses have been found for this mineral that the industry has become safely established. Seaweed was burnt to kelp as a source of alkali, but tariff reductions and chemical discovery killed the industry and deprived the western seaboard of Scotland of its main source of income. Kelp was later used as a source of iodine, with potash as a by-product, but the extraction of iodine from Chilean saltpetre sounded the death knell of the industry. Limestone grinding was officially encouraged in Scotland only for agricultural purposes, yet the price of ground limestone might have been reduced if other uses for the raw material had been found. The future of the slate industry depends among other things upon uses being found for the waste.

Mineral deposits are sometimes worked by firms solely for their own requirements; other uses of the mineral are not sought, and when a better or cheaper source of supply is found the deposit may be abandoned.

(ii) *Varietal utilisation.* Deposits of minerals vary widely in purity and physical properties. The aim should be to make use of the varietal differences in raw material to the best advantage. Variation may occur within a deposit or between different deposits. When variation occurs within a deposit care should be taken to separate the significant qualities. In barytes mining, for example, contaminated ore should be kept apart from ore which

[1] Report of a discussion arranged by Section B (Chemistry) and held on September 1, 1947, at the Annual Meeting of the Association in Dundee.

can be readily purified. To do this effectively, close technical collaboration is required between miner and processor. Peat varies to a great extent vertically : diatomite deposits probably do also.

Coloured terms such as ' poor quality ' sometimes prevent a deposit from being worked. Talc which is poor in pharmacy may be excellent in, shall we say, foundries. A ' poor deposit ', which was bought and abandoned by a firm who thought it a commercial nuisance, was found later to be better for three or four purposes than the major, better known deposit. If several deposits are worked in competition by different firms, the products tend to find applications for which each is most suitable, though geographical considerations will also favour the nearest ; nevertheless, small or impure deposits are at a great disadvantage commercially unless the firms working them can have equal access to the scientific and technical knowledge available to larger companies.

(iii) *Complex utilisation.* In complex utilisation the raw material is broken down into constituent parts which are different from each other chemically or physically. In the United States crude petroleum was once used only as a fuel, but to-day 80 to 90 per cent. of the oil is converted into high priced products many of them for use in the chemical industry. Similarly the groundnut once yielded only oil and cattlefood. Now the I.C.I. at Ardeer have shown that it can also yield a protein, which they have converted into a new wool-like fibre, called Ardil. New and better uses for oil, residue and husks will be found. Seaweed now yields alginic acid and its salts in Scottish factories, and these have many uses ; but the industry will be on a sounder basis when research points the way to extraction and use of the other constituents, such as potassium, iodine, mannitol and cellulosic matter.

The burning of coal in open grates is now recognised as wasteful but far more development work should be directed towards its complex utilisation, providing us with smokeless fuel, gas and multitudinous chemicals.

The same aim should be applied to all complex raw materials. Even a mineral like felspar can probably yield potash and a variety of siliceous and aluminous products, such as alumina, silica gel, soluble salts, adsorbents, base-exchange materials and so on.

Peat undoubtedly lends itself to complex utilisation, and so does bracken. When studying peat and seaweed, we see at once that there are several entirely different ways in which the material may yield a variety of products. In other words several different peat industries are possible. Thus wax can be extracted with solvents from certain peats and the residue converted into active carbon or distilled. Carbohydrate-containing materials may be converted into a range of oils by alkaline hydrolysis and hydrogenation. Steam distillation, low temperature and high temperature distillation yield different ranges of products. The art of carefully separating constituents should surely receive more attention than the thermodynamically more wasteful processes of complete breakdown followed by synthesis. At least there is room for both lines of attack.

The older term ' extractive industries ' could be abandoned now because it implies that the residue is waste or a nuisance. The term ' by-product ' may also give rather a false value.

When residues are accumulated because no use has yet been found for them, they should be kept clean and separate from other substances, so that they can be worked in the future. Thus coal ashes containing germanium could be stored for future use. The whole question of waste-utilisation has to be continuously reviewed, so as to save unnecessary imports. The world cannot afford to waste its substance.

(iv) *Co-operative development.* Many local resources would never be developed at all unless plant or management or laboratories were shared. A simple example is a fine-grinding installation to which bulk lots of minerals go for treatment on their way to the consumers' factories. The requirements of finely-ground talc, quartz, feldspar, marble, limestone, slate, mica, asbestos, and so on, taken together, might very well justify the erection of a costly specialised plant.

The production of basalt chips for road and concrete making and ground agricultural limestone can sometimes be carried out under one roof. Or marble terrazzo chips and limestone.

Drying plant could also be used for drying crops of seaweed, grass, oats, etc., in their season, and special varieties of peat, sphagnum moss, fishmeal, and other things at other times. The drying programme would have to be worked out to conform with nature and her seasons.

Labour and transport can also be more effectively used if industries co-operate in management. Competition for labour can be most undesirable, especially where agriculture is liable to suffer.

Stages in research and development. The table on p. 22 shows the stages which can be recognised in the development of raw materials. The scheme outlined by Dr. Robert P. Russell (4) as representing the part played by a large research and development company is included.

TABLE I

(R. P. Russell.)

CONTINUITY OF DEVELOPMENT			
↓	SURVEY		NATURAL AND HUMAN RESOURCES.
	ANALYSIS LABORATORY-SCALE	LARGE FIRM	SCIENTIFIC DISCOVERY, INVENTION AND RESEARCH, (TEST-TUBE).
	PILOT-PLANT		DEVELOPMENT, (PILOT-PLANT).
			ENGINEERING APPLICATION OF DEVELOPMENT.
	FACTORY		PRODUCTION MANAGEMENT AND LABOUR, SALES AND DISTRIBUTION: EXECUTIVE MANAGEMENT.
	REGION		ECONOMIC AND POLITICAL CLIMATE.
	WORLD		

If we are to see the world's resources used for the benefit of mankind, there must be continuity of development, a most important principle. The large firm covers a wide range in the process of development, and smaller firms cover only a small part of the range. It must be the object of Government to help to fill up the gaps and so maintain the continuity.

Survey. Mineral resources are mapped and described by the Geological Survey in this country, but information regarding the world's resources is still very inadequate. If an area is to be developed the resources always have to be examined in much greater detail; resource surveying should be the very basis of regional development. The Tennessee Valley Authority had to multiply the survey work of the States before they could initiate development and the great importance attached to resource surveying in Russia is well known. In Scotland littoral and sub-littoral brown seaweed have been surveyed, but there is no general botanical survey. It is consequently difficult to get peat and bracken industries started, because the primary information has not been collected.

The Land Utilisation Survey provided a useful historical document: but we need a great extension of soil surveys and maps which show the potentiality of the soil. Under survey might be included the collection of statistics; and reference should be made to the Third Statistical Account in Scotland.

Information about resources gathered from all sources should be made more readily available by use of modern methods of documentation.

Analysis. The fact that there is no analyst attached to the Geological Survey in Scotland lends cogency to the argument that there should be a strengthening of the staff of the Macaulay Institute for Soil Research to make an Institute of Geochemistry. Physical as well as chemical properties of raw materials have to be measured.

Laboratory-scale work on processes of extraction, refining, separation and utilisation of the whole of the material must then be carried out, followed in some cases by *pilot-plant development* of promising processes. This is where the chemical engineer comes in.

Factory. The management of the factory development is very well treated by Dr. Russell (4). The siting of the works should be determined by what is socially desirable and economically reasonable, *i.e.*, according to the requirements of *Regional Development*, the classic example of which is in the Tennessee Valley (3). In Britain, the only reports on the integration of natural resources and chemical industries have been made for W. C. Devereux, on South Wales and West Cumberland (5, 6). Unified resource development has the greatest significance for the opening up of Scotland's desolate areas.

Distribution and Scale of Operation. Resources may be of international, national, or local importance.

(i) If one country has more of a raw material than other countries which are deficient in it, the raw material assumes international importance. According to Atlantic Charter (1) and Hot Springs tenets these should be distributed fairly throughout the world according to the genuine peaceful needs of all parts. The country of origin should also benefit. Standards of health, housing and education should be raised by proper allocation of profits. Reserves should be set aside for financing the change-over to other industries when a deposit is finally worked out. Alternative occupations should preferably be found during the hey-day of the exploitation.

No country can afford to export all its substance ; monoculture devastates the land. Thus the sheep culture of the Highlands should be diversified by the development of other resources.

(ii) *Medium-sized or well-distributed resources.* Although Scientific knowledge is widely disseminated, technical knowledge and experience are not so. Useful methods in resource development should one day be the property of mankind as a whole.

There has been some tendency for countries to become less dependent on the rare deposits, so patchily distributed throughout the world, because technical advance has shown how to make use of the air, sea, minerals, and agricultural products which are ubiquitous or very widely spread. The manufacture of fertilisers from air, magnesium and bromine from seawater, aluminium from clay, and alcohol from crops, and similar developments lead to a state of greater self-sufficiency.

(iii) Small deposits also have their part to play, though their interest is local. They provide alternative occupation, often where it is needed, and they can be worked in conjunction with other resources. They provide a training ground for technicians, and variety stimulates advance. They are a reserve in times of emergency. They should not be exhausted in a few years for quick profits, but should be worked to last for one or two generations at least. It is significant that small deposits are worked even in countries possessing very great resources of the same kind, usually for local consumption. Technical assistance should be freely given to small enterprises in this class.

Man's place in resource development. At present almost anyone with capital, however ignorant, may obtain sole rights to work a mineral deposit for his own profit. Much has been achieved by this method but on the whole it has mainly led to devastation. The scale of operation usually bears no relation to national or regional needs. Individuals or firms should be trustees of the resources, but overriding guidance is necessary.

The greatest single factor in resource development is the people. The inhabitants of a resource-bearing region should have some control over its management. It is in their interest to preserve their heritage, whereas external organisations of consumers are less concerned with long-term continuity of supplies and regional welfare than with getting the cheapest source of supply.

Regional Development in Relation to Scottish Resources and Chemical Industry. There are five or six natural divisions in Scotland. In these regions the geographical, geological, industrial and agricultural patterns are widely different. The integration of chemical industries and natural resources therefore can be considered as a number of distinct regional problems. The Highland area, for example, is dominated by waterpower development, most of which will have to be used within the region if the region is to become prosperous. Organisation is required to examine the other resources of the region in relation to its needs. One might ask whether the limestone of Torrlundy and peat coke, which has a lower ash content than coal coke, can be used for the manufacture of calcium carbide and cyanamide. It is extremely unlikely that such a theoretically possible combination would arise by the mere attraction of industry to the region. Only an authority with powers could engender such a development. Furthermore, the building of the required number of houses and the introduction of the right type of labour demand unified resource development. Centralised departmental administration is a proved failure so far as Scottish resource development is concerned.

The Geological Regions and their Minerals

THE Highland Boundary Fault and the Southern Uplands Fault, said Mr. T. H. Whitehead, Assistant Director of the Geological Survey, divide Scotland into three geological and geographical regions in which different conditions affect the development of mineral resources (7, 8).

In the ' Midland Valley,' between the two faults, are found the chief sources of hydrocarbons, namely, nearly all the coal, cannel shale, all the oil-shale and such natural gas as has been proved. In the same region are the best fireclays and the bauxitic clays, as well as ganister and silica rock ; but, in the refractory class, the Highland region offers quartzite for silica, dolomite, brucite marble, and chromite in association with antigorite, serpentine and talc.

Sand and silica rock for glass making are, again, found chiefly in the Midland Valley ; but the best quality comes from Loch Aline, in the Highland region. Feldspar sufficient for wartime requirements was obtained in Harris and the northern Highlands, but has proved uneconomic under normal conditions.

In the Midland Valley the better limestones have been much worked and further supplies would have to be obtained by mining. In the Cambrian and metamorphic limestones of the Highlands, however, there are large reserves of good quality. The association of the limestones of the Midland Valley and Southern Scotland with argillaceous rocks and sandstones might suggest possibilities for the cement industry and for the manufacture of rock wool.

The mining of zinc ore might be revived in Southern Scotland and possibly in one or two localiti in the Highlands. Barytes is worked in the Midland Valley and this region seems to offer the best prospect for future supplies.

The most notable deficiencies are rock-salt, china clay, gypsum or anhydrite, and metallic ores in quantity ; the greatest concentration of presently worked resources is in the Midland Valley which has therefore attracted population from the other areas. Coal represents about 90 per cent. of the total value of all minerals raised in Scotland, and the reserves are estimated to be 7,652 million tons, and to last 250 years, though some special types are being squandered. Hydro-electricity and better transport facilities may enable the large masses of non-metallic minerals in the Highlands to be utilised. In any case there is an urgent need to set up laboratories to study and develop uses for Scottish mineral materials, not only those which are familiar, and accessible, but, in the interests of national economy, those which have been up till now too inaccessible.

Hydro-electric Power Utilisation

Mr. A. G. E. Robiette dealt with the industrial uses of hydro-electric power in relation to the present developments in the North of Scotland (9).

The basis of industrialisation is power, whether this be produced from coal, oil, or water. Certain countries short of fuel have developed hydro-electric resources and have built up large electro-chemical and electro-metallurgical industries in many cases using, to a large extent, imported raw materials. They have specialised on processes and products which use large quantities of electrical energy in their manufacture, and certain of these products can only be made practically by such methods.

Great Britain, an industrial country whose economy relies upon coal, has always so far imported these products on a large scale. The principal exception is the production of aluminium in Scotland, and the war-time emergency production from steam power of calcium carbide, ferro-silicon and magnesium.

A summary of the processes involved in the manufacture of the principal products is given, together with estimates of production figures and power requirements. The consumption of indigenous raw materials is indicated, and the significance of this factor, together with the setting-up of subsidiary or related industries is emphasised.

Mr. Robiette referred to the present policy that after power has been allocated for Highland electrification and for sale to the Central Electricity Board the balance should be available for " large power users having a demand of not less than 5,000 kw." Such industries can contribute to the regeneration of the Highlands. Norway has founded her great electrotechnical industries with cheap power and mostly imported raw materials. The higher cost of electricity in the Highlands may be to some extent offset by the greater efficiency of the most modern installations, by low interest charges, and especially by integration to form a cohesive industrial scheme in which the by-products of one industry are used as the raw material of another. Other advantages are consumption of power near to the source of generation, and the use of some local raw materials. There is no reason why the execution of such a scheme need deface the beauty of the Highlands. Arguments were made for a scheme of production outlined in Table II.

Table II

Suggested production plan for Scottish hydro-electric industries				Minerals required from Scotland	
	Production Tons/year	Energy Consump. KWH × 10^6	Value £	Tons Per annum	
Ferro Alloys	45,000	360	1,500,000	Silica rock	100,000
Calcium carbide	30,000	100	700,000	Limestone	60,000
Graphite and carbon products ; carborundum and abrasives	55,000	190	1,200,000	Silica sand	2,500
Aluminium	70,000	1,340	5,250,000	Dolomite and other rocks	3,000
Fused products, glass, etc.	10,000	10	500,000		
Electrochemicals	20,000	90	600,000		
		2,090	£9,750,000		

Chemical Industry in Scotland

PROFESSOR W. M. CUMMING reviewed the background from which the chemical industry in Scotland has emerged to its present position. Some historical dates are given in Table III. From an industry connected with textiles, chiefly linen and cotton, it passed to one associated with the heavy engineering industries. The chemical industry ultimately centred largely round the famous St. Rollox works (10, 12).

The present position in heavy chemicals and fertilisers, refractories and ceramics, cement, glass, paints, pigments, compressed gases and bichromates was reviewed ; on the organic side, tar products, explosives, dyestuffs, fermentation, fine chemicals and pharmaceuticals (13), artificial fibres, leather, plastics and rubber, vegetables oils, paper and fermentation industries were discussed. In some cases considerable expansion was forecast, and attention was directed to the hitherto neglected raw materials and to the hydro-electric possibilities in the organic and electrochemical industries. The origin of the main raw materials used by Scottish chemical industries is given in Table IV (11, 14).

TABLE III.—SOME DATES IN THE SCOTTISH CHEMICAL INDUSTRY

1587	Licence to make paper.
1749	Sulphuric acid : Roebuck.
1759	Carron Iron Co. founded.
1772	252 linen factories.
1781	Coal distillation. Lord Dundonald's patent.
1785–8	Potassium hypochlorite : Watt. Bleaching powder : Tennant.
1790	Turkey-Red industry founded.
1797	St. Rollox Works founded.
1800	134 cotton factories.
Ca1800	Edinburgh drug firms.
1831	Bichromate industry founded.
1850	Oil shale : Young's patent.
1856	Pullar's of Perth help Perkin.
1859	First synthetic dyeworks, Glasgow.
1871	Nobel's, Ardeer, founded
1876	Mercury fulminate, Polmont.
1894	British Aluminium Co. founded.
1919	Morton's dyeworks, Grangemouth.
1922	Synthetic phthalic anhydride.
1928	Monastral blue.
1929	Viscose rayon, Jedburgh.
1942	Mepacrine manufacture.
1946	Paludrine manufacture.
1947	Ardil, groundnut protein fibre.

TABLE IV.—SCOTTISH CHEMICAL INDUSTRIES ARRANGED ACCORDING TO SOURCE OF MAIN RAW MATERIALS

1. All or mainly imported	2. Some produced locally	3. Once local, now in groups 1 and 2	4. Local supplies since foundation	5. Developments possible in local resources
Cotton	Wool	Linen 1	Coal	Coal products
Sulph. Acid	Paper	Hypochlorites 1	Tar products	Electrochemicals
Turkey red	N.-Fertilisers	Alkalis 1	Oil-shale	Methanol and formaldehyde
K.-Fertilisers	P.-Fertilisers	Iodine 1	Ca-Fertilisers	Seaweed
Paint	Cement	Iron and Steel 2	Firebricks	Peat
Aluminium	Glass	Soap 2	Silica bricks	Forestry Products
Magnesite	Solvents	Tanning Materials 1	Dry Ice	Minerals, *eg.*, dolomite, talc, felspar, etc., zinc and lead
Chromebricks	Explosives	Leather 2	Compressed gases	Plastics
Chrome salts	Carbon Black			
Petroleum	Fermentation			
Galenicals	Chemical Plant			
Rubber				
Art. fibres				
Veg. oils				

Scotland is fortunate in possessing a good chemical plant manufacturing industry. Indeed this industry may be said to have started in Scotland. Facilities and experience are available for the design and production of the most complicated plant and the chemical industry need have no fear of the future on this score.

The smaller chemical manufacturer in Scotland is not yet fully appreciative of the advantages of research, and a plea is made for the employment of more scientists in the chemical industry in Scotland, so that it may maintain its position in the future industrial development of the country.

In Scotland there is an abundance of

resources, good land, crops, forests, rivers, minerals, coal, peat, and so on, and a wide range in climate ; it is a sad reflection on the organising ability of Britain that Scottish scientists and technicians are forced into exile rather than given a chance of studying and developing the riches of their own country.

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(12) FLECK, ALEXANDER : *Commemoration Lectures for the Bicentenary of the Inauguration of the Teaching of Chemistry in* 1747 *at the University of Glasgow, No.* 3, (23/5/1947) (in press).

(13) CUMMING, W. M. : ' Scotland's Contribution to Fine Chemicals,' *Chemist & Druggist Export Review* (July 1947).

(14) Report of Committee on Chemical Industry in Scotland. *Scottish Council (Development and Industry)* (in press).

OPERATIONAL RESEARCH

BY PROFESSOR P. M. S. BLACKETT, F.R.S.

THE technique of the scientific analysis of operations of war, particularly as developed in Great Britain during the late war, has been the subject of a considerable amount of public discussion, as for instance at the recent meeting of the British Association at Dundee.[1] The interest in these developments lies partly in the practical importance of the results achieved and partly in the feeling that similar methods might be applied with success to some of the urgent problems of the post-war world. Short accounts of some aspects of the wartime development of operational analysis have appeared in various publications,[2,3,4] but no systematic account has yet been published, though some are in preparation.[5] While awaiting these fuller accounts, permission has been obtained to publish two notes written by the author during the war, in which some of the principles of the organisation of the operational research sections and the methods of analysis, are set out in some detail.

The first of these, entitled ' Scientists at the Operational Level,' was written in December 1941, in order to inform the Admiralty of some of the developments which had occurred in the Operational Research Sections already established at Fighter, Anti-Aircraft and Coastal Commands. It so happened that this hurriedly and somewhat flippantly written document received subsequently a rather wide circulation in Service Departments both in this country and also in the United States, where it seems to have had some influence on the setting up of similar organisations.

The second document, under the title ' A note on certain Aspects of the Methodology of Operational Research ' originated in 1941 as an attempt to set out for the benefit of new scientific recruits to the operational research sections, some of the principles that had been found to underlie the work of the first two years of the war. The text as reproduced here, dates from May 1943. A few notes have been added to the original documents. As the nearest existing approach to a ' text book ' of operational research, it also received a fairly wide circulation, and has, along with the former document, been fairly extensively quoted in various official and semi-official documents. It must be emphasised that these two papers cover only a small part of the great field of operational research

[1] Reported in *The Advancement of Science*, No. 16, Jan. 1948.

[2] Charles Kittel, ' The Nature and Development of Operational Research." (*Science*. 105. Feb. 1947).

[3] C. H. Waddington. (*World Review*, June 1945).

[4] Blackett : Memoir of E. J. Williams, F.R.S. Obituary Notice of Royal Society, Feb. 1947.

[5] A fairly full account has recently been published in *Science at War*, Crowther & Widdington, H.M. Stat. Office, 1947.

as developed in Great Britain and the United States during the war and that very many important achievements are not mentioned at all. For instance, the examples given were chosen rather haphazardly and mainly with a view to illustrating points of methodology.

There are surely lessons to be learned from these war-time developments that may help us to tackle wisely some of the problems of peace. It is hoped that the publication of these documents will stimulate such application. Of more theoretical interest is the general problem of the limits of predictability in the inexact sciences. For instance, some parts of modern economics seem to use a variational technique closely analogous to that described in the second paper.[6]

The writer wishes to take this opportunity to pay tribute not only to his scientific colleagues who were engaged with him directly or indirectly in this new development, but also to those senior officers of all three fighting services, whose sympathy, understanding and encouragement were the essential basis without which the development could not have taken place. Among the latter, the writer wishes to mention particularly, General Sir Frederick Pile, Air Chief Marshal Sir Philip Joubert, Air Chief Marshal Sir John Slessor, and Admiral Sir George Creasy. It is only possible to mention a few of the scientists whose influence in the formulation of the ideas expressed in the two documents have been paramount. From the earlier formative period there were Sir Henry Tizard, Sir Robert Watson Watt, A. P. Rowe and G. H. Larnder. During the latter period the names of the late Sir Ralph Fowler and E. J. Williams, L. H. Bayliss, Henry Whitehead, C. H. Waddington, H. R. Hulme, E. C. Bullard, Andrew Huxley and Charles Kittell, stand out prepreminently.

I wish to express my gratitude to the Minister of Defence for permission to publish these two papers.

[6] For instance, N. Kaldor's Appendix III to Sir William Beveridge's *Full Employment*.

Document I.

SCIENTISTS AT THE OPERATIONAL LEVEL (1941)

1. The object of having scientists in close touch with operations is to enable operational staffs to obtain scientific advice on those matters which are not handled by the service technical establishments.

Operational staffs provide the scientists with the operational outlook and data. The scientists apply scientific methods of analysis to these data, and are thus able to give useful advice.

The main field of their activity is clearly the analysis of actual operations, using as data the material to be found in an operation room, e.g., all signals, track charts, combat reports, meteorological information, etc.

It will be noted that these data are not, and on secrecy grounds, cannot, in general, be made available to the technical establishments. Thus, such scientific analysis, if done at all, must be done in or near operation rooms.

The work of an Operational Research Section should be carried out at Command, Groups, Stations or Squadrons as circumstances dictate.

2. Scientific Analysis of Operations

To what extent is it useful to do analysis of operations in a more scientific manner than is done normally by service specialist officers?

Experience over many parts of our war efforts has shown that such analysis can be of the utmost value, and the lack of such analysis can be disastrous. Probably the main reason why this is so, is that very many war operations involve considerations with which scientists are specially trained to compete, and in which serving officers are in general not trained. This is especially the case with all those aspects of operations into which probability considerations and the theory of errors enter. Serving Officers of the highest calibre are necessarily employed in important executive posts, and are, therefore, not available for *detailed* analytic work.

(i) *Schedule of Typical Operational Research*

The records of some war operation (e.g. air attacks on U-boats for the previous six months) are taken as the data. This is analysed as quantitatively as possible, and the results achieved are 'explained' in the scientific sense, i.e. brought into numerical relation with the other operational facts and the known performance of the weapons used. When this has been done, consideration is given to possible modification of the tactics to improve the operational results.

The first step—that of collecting the actual data—is by itself of enormous importance, for it is not uncommon for operational staffs to be unacquainted with what is actually being achieved. An Operational Research Section is not in general concerned with 'hot news,' though they should be prepared to so concern themselves if specifically requested to do so.

(ii) *On the Validity of Deductions from Observations*

A typical problem is as follows :—a weapon A is calculated by a service technical department to be 50 per cent. more efficient than a weapon B. Actual operations over a given period show, say, 2 successes for A and 4 for B. Does this prove that B is a better weapon than A ?

Such points arise continually and require the highest scientific judgment to resolve. In particular a grasp of fluctuation phenomena (i.e. Poisson's Distribution) is required. If the average number of hits on some target in a given time is m, then (on certain assumptions) the chance that exactly x hits will be obtained in the same time is

$$\frac{e^{-m}m^x}{x\,!}$$

(iii) *Value of Scientific Confidence and Numerical Thinking*

The scientist in considering an operational problem, very often comes to the conclusion that the common sense view is the correct one. But he can often back the view by numerical proof, and thus give added confidence in the tactics employed.

Or when two alternative qualitative views, ' A is best ' ' B is best ' are in dispute, he can often resolve this numerically into some such statement as that ' A is x per cent. better than B in January and y per cent. worse in June.'

In fact, the scientist can encourage numerical thinking on operational matters, and so can help to avoid running the war by gusts of emotion.

(iv) *Operational Experiments*

Since new weapons and devices are inevitably put into service relatively untested, the first few months of the use of a new device must be considered as an extension of its development trials. An Operational Research Section can function usefully here in a liaison capacity between the operational staff, the technical department which produced the device, and the development unit which tested it.

Further it is often possible, by collaboration between Controllers and the staff of an Operational Research Section, to arrange operations on certain occasions so as to obtain data to clarify some doubtful point. For instance, the relative merits of different forms of anti-submarine sweeps by aircraft is a matter of (*a*) mathematical calculation, (*b*) test by actual operations, perhaps over a long period of time.

3. Distribution of Reports on Operations

One of the functions of an Operational Research Section is clearly to write periodical reports on various aspects of operations. Except when secrecy questions prevent, these should be given a wide circulation, e.g. in the Air Force to Squadrons to be read by the aircrews. In this way, the tactical education of the men on the job can be raised.

4. Operational Requirements

One of the most important duties of a Command is to state its requirements for new devices and weapons. Such requirements are passed, in general, through a department of a Ministry (which acts partly as a filter room, partly as a specialised department and partly as a post office) to a service technical establishment.

The only places in this chain where the real operational facts are known is at the Command Groups and Stations. Unless the operational requirement is considered scientifically at the Command jointly by the operational staffs and scientists, it is possible that the operational requirements decided on will not correspond (*a*) to the real need, (*b*) to the technical possibilities.

In other words, an Operational Research Section can act usefully by interpreting

(*a*) the operational facts of life to the technical establishments, and

(*b*) the technical possibilities to the operational staffs.

A considerable wastage of war effort has occurred through lack of this joint discussion.

Nothing in this section or in section 2 should be taken as implying that an Operational Research Section should be the only channel by which a Technical Establishment obtains operational experience—on the contrary the direct contact between a Technical Establishment and operational units is generally essential.

5. Organisation and Personnel

An Operational Research Section should be an integral part of a Command and should work in the closest collaboration with the various departments at the Command.

The head of the Operational Research Section should be directly responsible to the Commander-in-Chief and may with advantage be appointed as his scientific adviser.

A considerable fraction of the staff of an Operational Research Section should be of the very highest standing in science, and many of them should be drawn from those who have had experience at the Service Techincal Establishments.

An Operational Research Section which contents itself with the routine production of

statistical reports and narratives will be of very limited value. The atmosphere required is that of a first-class pure scientific research institution, and the calibre of the personnel should match this. All members of an Operational Research Section should spend part of their time at operational stations in close touch with the personnel actually on the job.

6. New Devices

'New weapons for old' is apt to become a very popular cry. The success of some new devices has led to a new form of escapism which runs somewhat thus—'Our present equipment doesn't work very well; training is bad, supply is poor, spare parts non-existent. Let's have an entirely new gadget!' Then comes the vision of the new gadget, springing like Aphrodite from the Ministry of Aircraft Production, in full production, complete with spares, and attended by a chorus of trained crews.

One of the tasks of an Operational Research Section is to make possible at least an approach to a numerical estimate of the merits of a change over from one device to another, by continual investigation of the actual performance of existing weapons, and by objective analysis of the likely performance of new ones.

The actual operational effectiveness over a period of time of any weapon can usefully (even if platitudinously) be considered as the product of three factors; the first $N(t)$ is the number in use, expressed as a function of the time; the second P is the scheduled performance of the weapon; and the third $S(t)$ is the average state of serviceability and training, i.e., the actual performance expressed as a fraction of the schedule. The probable form of $N(t)$ could be obtained from the production statistics of existing weapons. Relatively little is known of the form of $S(t)$, but probably a good first approximation would be to take $S(t) \propto (1-e^{-t/T})$ where T is of the order of 2 months to 1 year according to the type of gadget. Some operational research might usefully be directed toward elucidating this function. One could then attempt a numerical estimate of the gain or loss involved in the change over from one device to another, and so attempt to avoid the unduly heavy overhead costs of too rapid change over.

7. In general, one might conclude that relatively too much scientific effort has been expended hitherto in the production of new devices and too little in the proper use of what we have got. Thus, there is a strong general case for moving many of the best scientists from the technical establishments to the operational Commands, at any rate for a time. If, and when, they return to technical work, they will be often much more useful by reason of their new knowledge of real operational needs.

Document II.

A NOTE ON CERTAIN ASPECTS OF THE METHODOLOGY OF OPERATIONAL RESEARCH (1943)

1. Introduction

Now that more and more of the operations of war are being analysed by teams of operational research workers, it may be of some value to discuss certain methods of approach which have proved fruitful in practice. It is hoped that these notes may assist new operational research workers to extract rapidly from any field of work the greatest possible amount of useful information.

It is not, of course, suggested that the very obvious common sense of the variational methods discussed below is in any sense novel. On the contrary, they are in general use, implicitly at any rate, in those branches of science whose subject matter has similar characteristics. These characteristics are that a limited amount of numerical data is ascertainable about phenomena of great complexity. The problems of analysing war operations are almost all of this type and are therefore rather nearer, in general, to many problems, say, of biology or of economics, than to most problems of physics, where usually a great deal of numerical data is ascertainable about relatively simple phenomena. However, operational research, like every science, must not copy in detail the technical methods of any other science, but must work out techniques of its own, suited to its own special material and problems. These techniques must not remain rigid but must change with the nature of the problems.

One obvious characteristic of operational research, as at present practised, is that it has, or should have, a strictly practical character. Its object is to assist the finding of means to improve the efficiency of war operations in progress or planned for the future. To do this, past operations are studied to determine the facts; theories are elaborated to explain the facts; and finally the facts and theories are used to make predictions about future operations. This procedure ensures that the maximum possible use is made of all past experience.

The main fields of operational research can be classified under the following headings, the study of weapons, the study of tactics, and the study of strategy. The first consists mainly in analysing how and why existing weapons perform as they do, with the object of finding out how they could be improved. The second consists in analysing the various tactical methods in use, with the same object of finding methods of improving them. The third consists in studying the results achieved by various types of operation, and the cost in the resources of war of achieving them. The actual form of the method of variational analysis lends itself immediately to the calculation of 'marginal' profits and costs—which is in general what is required.

Predictions about the future are of course always subject to much uncertainty, but experience has shown that many more useful quantitative predictions can be made than is often thought possible. This arises to a considerable extent from the relative stability over quite long periods of time of many factors involved in operations. This stability appears rather unexpected in view of the large number of chance events and individual personalities and abilities that are involved in even a small operation. But these differences in general average out for a large number of operation and the aggregate results are often found to remain comparatively constant. (Appendix A. 4.)

The somewhat formal—even pedantic—character of some of the following discussion is chosen for the sake of brevity and generality. It will have achieved its object if, on the one hand it encourages research workers to tackle problems which might otherwise be put aside as too complex, or, on the other hand, if it leads to apparently simple problems being recognised in their true complexity. Although the main object of operational research is to make useful predictions, it has also an important function in assessing the possibilities of prediction and in calling attention to fields in which no or little quantitative prediction is possible.

The examples given in the Appendices illustrate some of the arguments of the note. Time has not permitted the compilation of a comprehensive set of examples.

2. Operational Research Procedure

When embarking on a new problem of operational research, the first step is usually to collect as much numerical data about the operations as possible. But much data remain unavailable, either because no records exist, or because their collection is impracticable. Thus, a very incomplete numerical picture, in the form perhaps of tables or curves representing some results of the operations as a function of some few variables, is all that can usually be obtained.

This first step alone may be of the greatest importance and lead to practical conclusions of great value. For the suitable presentation of the actual facts of past operations, without any interpretation, may be so striking as alone to compel reconsideration of tactics and methods. (See Appendices B.1 and B.5.)

But to go farther, it is clearly necessary to relate these observed results to (*a*) the actual properties of the weapons employed, and (*b*) the actual tactics employed. In other words, the object is to find a scientific explanation of the facts. Only when this is done can the two main objects of the operational research be attained. These are the prediction of the results of new weapons and of new tactics.

3. The a Priori Method

One possible method of procedure is to attempt to find general solutions to certain rather arbitrarily simplified problems. In times of peace, when up-to-date numerical data on war operations is not available, this method may alone be possible. This procedure is to select, out of the numerous variables of a real operation of war, certain important variables which are particularly suitable for quantitative treatment, and to ignore the rest. Differential equations are then formed and solutions obtained.

Certain results obtained by this method are of great interest. An example is Lanchester's N^2 Law (Appendix D). But it is generally very difficult to decide whether, in any particular case, such a 'law' applies or not. Thus it is often impossible to make any practical conclusions from such an *a priori* analysis, even though it be of theoretical interest.

Another difficulty with the *a priori* method is that when a solution in a certain number of variables has been obtained, and it is found necessary to introduce an additional variable, very often a completely new start must be made. In fact the method seldom lends itself to the solution of problems by successive approximations.

4. The Variational Method

The more common sense procedure is to abandon the attempt to construct from 'first principles' a complete imaginary operation *something like* the real one under investigation, and to replace it by an attempt to find, both by experimental and by analytical methods, how a real operation would be altered if certain of the variables, e.g., the tactics employed or properties of the weapons used, were varied.

Suppose the result of any operation of war is denoted by quantities Y_1 Y_2 etc., called the yields. Then these yields must be considered as functions of a large number of operational parameters or variables X_1 X_2 . . . X_n. Some of these can be given a quantitative measure but some can only be expressed qualitatively. Any attempt to find the form of such a function :

$$Y = F(X_1 \ldots X_n) \qquad (1)$$

from first principles is useless, in general, owing to the complexity of the problem and the non-quantitative nature of many of the variables (e.g. Appendix A.1).

The common-sense procedure is to use the result Y of some past operation under known conditions to predict the result Y′ of a future operation under new conditions. If the new conditions differ too widely from the past conditions, the problem of calculating the yields becomes, in effect, an *a priori* one, and, as already explained, such problems are generally insoluble.

But when only relatively small changes in some only of the variables are anticipated, a fairly accurate answer is often attainable by investigating the variation of the yields with the relevant variables. Such predictions can be made when it is possible to determine the partial differential coefficients :—

$$\frac{dY}{dX_n}$$

of the yields with the different variables. In some cases the complete form of the partial function $Y = f(X_n)$ may be determinable, but generally this is not the case, and only the first derivative can be found.

If these differential coefficients can be determined, then the operational effect of possible changes in weapons, tactics and training can be estimated quantitatively, giving a predicted yield :

$$Y' = Y + \frac{dY}{dX_1} dX_1 + \frac{dY}{dX_2} dX_2 + \text{etc.}$$

As is pointed out above, it is often not worth while to attempt to predict at all accurately the effect of large changes of variables, since it is usually only for small changes that the different differential coefficients can be considered as constant or as independent. In certain cases (see section 7. 1), however, a causal relation, and in other cases a tactical relation (section 7. 2) between some of the derivatives is known, and can be taken into account.

It must be remembered that some of the variables (e.g. many of those listed for a particular problem in Appendix A. 1) are not easily susceptible to numerical estimation, and so no numerical values for the differential coefficients are obtainable. But this does not invalidate the use of those derivatives which can be given a numerical value. This fact is in marked contrast to the case of the analytic (*a priori*) approach to the problem where lack of knowledge of the effect of any one non-quantitative variable (e.g. morale) can make any significant solution impossible.

The variational method under discussion must be considered as the formal treatment of the common-sense approach. It is applicable whenever operations have been in progress and tactics have been sufficiently stabilised, as they often are for months at a time, for definite experimental data on the results of past operations to be obtained. It should be remembered that the technical instruments of warfare do not usually change rapidly owing to the long duration of development and production. And even tactics cannot usually change very fast owing to the necessary duration of training. Thus the condition of relative stabilisation of operational technique is quite often fulfilled.

In the method of procedure under discussion, any new tactical situation (B) is to be treated as a *variation* of some old one (A) about which, at any rate, some facts are known. Even though the two situations may not be very similar, and so the differentials dX_1 dX_2 etc., by which one derives the yield of B from that of A, may not be in fact small, the results may sometimes be fairly reliable, provided common sense and judgment are used (e.g. Appendix C. 1). This is particularly the case where analytical methods can be used to determine, not only the differential coefficients, but the actual form of the relevant partial functions $Y = f(X_n)$ etc.

It must not be thought that any explicit reference to the differential or variational terminology is demanded in the working out of most problems, which usually follow straightforward and common-sense lines. But the cultivation of the method of thinking differentially about operational problems and of prediction by the variational method does seem of definite value.

Thus, the first attack on any operational problem is often to estimate as many of the derivatives as possible : first the *tactical* derivatives to judge what changes of *tactics* would lead to improved yields ; then the material derivatives to estimate the effect of improved *weapons*. Many mistakes have been made by inverting this order, e.g. a new weapon may be demanded which promises an improved yield over existing weapons with existing tactics, but which may prove to give a lower yield compared with existing weapons with improved tactics. Much of this type

of analysis reduces to the process of fighting a past campaign in imagination with improved weapons and tactics.

Expressed in geometrical language, the first task of operational research faced with a new operation, is to investigate the shape of the multi-dimensional surface

$$Y = F(X_1 \ldots X_n)$$

surrounding the point corresponding to a past operation, and to use this knowledge to predict the properties at a neighbouring point corresponding to a future operation.

5. Methods of Finding the Derivatives

5. 1. *Statistical Method.* In some cases the operational data is extensive enough and covers sufficient diversity of conditions to allow the coefficients to be deduced directly. This process is one of extrapolation from known data, and is clearly reliable in principle (Appendix A. 2). In practice, however, the observed yields are often so small numerically as to make random fluctuations important, and so to prevent significant values of the coefficients being deduced. Even when the *statistical* significance of some observed differential coefficient dY/dX has been established, it is very important to recognise that dY and dX are not necessarily directly *causally* connected. Rather they may, in some cases, be causally deducable from the variation of some third variable, which may not have entered explicitly into the analysis.

A well-known example is the 'Top Hat Fallacy.' Statistical investigation of the population of many cities would show that the wearers of top hats are significantly taller than the average. The missing causally effective variable here is clearly the higher average income and so better nutrition of the top hat wearing group.

5. 2. *Theoretical Method.* When, as is often the case, the total amount of data available is too small to make a reliable calculation of (dY/dX) possible, it is necessary to calculate these derivatives theoretically, by analysing in detail that part of the operation in which the variable under consideration plays the chief part (e.g. Appendix A. 3).

5. 3. *Mixed Methods.* A desired derivative $\frac{dY}{dX_1}$ may often be obtained from another operational derivative $\left(\frac{dY}{dX_2}\right)_{obs}$ by using (*a*) a theoretical, or (*b*) an experimental relationship between the assumed causally related increments δX, and δX_2.

Formally one can express the above method by the relation

$$\frac{dY_1}{dX_1} = \left(\frac{dY}{dX_2}\right)_{obs} \times \frac{\delta X_2}{\delta X_1} \qquad (3)$$

where $\delta X_2/\delta X_1$ is determined either theoretically or by special experiment. (Appendix A. 5 and 6.)

6. The Yield as a Product of Several Probabilities

Often the yield of an operation can be usefully expressed as the product of several probabilities P_1 P_2 . . . etc., so that, say

$$Y = P_1P_2P_3P_4$$

where the separate probabilities refer to more or less distinct phases of the operation. For instance in the simple case of air attack on a ship, the four main probabilities are (1) the chance of a sighting, (2) the chance the aircraft gets in an attack, (3) the chance of a hit on the ship, and (4) the chance that the hit causes the ship to sink.

In such cases, a comparison can be made of two past operations, or a prediction of the yield Y_2 of a future operation from that Y_1 of a past operation by the expression

$$Y_2 = \alpha_1\,\alpha_2\,\alpha_3\,\alpha_4 \ldots Y_1$$

Where α_1 α_2 etc., are the multiplying factors for the various separate probabilities.

Many important problems can be treated in this way (e.g. Appendix C).

7. Various Comments

7. 1. *Causally Related Differentials.* If the variation of some yield with some one variable is being investigated, one must remember to look for and take into account as far as possible all the resulting changes in other variables. To take a trivial example, if the geographical location of an operation is changed, the change in the average weather conditions, time of daylight, average visibility, etc., must be taken into account.

7. 2. *Tactically Related Differentials.* If a large change in an operation is contemplated it is to be expected that the enemy will react by changing his tactics or weapons. This will not in general occur at once, so that initially the enemy tactics may sometimes be considered as constant, but are likely to change in a manner to minimise the effectiveness of the new operation in a time measured in days to months.

7. 3. *Alternative Derivations.* When a new operation differs considerably from any past one, it may be the case that there are two or more past ones about equally different from the new ones. In this case the new operation can be treated in turn as a variation of each, and the results compared.

7. 4. *The Place of* a priori *Solutions.* These are often possible for especially simple problems, or partial problems, and of course should always be obtained where possible. They arise particularly often in the analysis of weapon performance, less often in tactical problems, and very seldom in strategical questions. This follows from the increasing order of complexity of these three fields.

7. 5. *On the Use of Rough Data.* No pregnant problem should be left unattempted for lack of *exact* numerical date, for often it is found on doing the analysis that *some* significant conclusions recommending concrete action can be drawn even with very rough data. In other cases, this is, of course, not so. But till the problem is worked out, one cannot tell.

It often happens that when the problem has been worked through in a very rough form, it is found that data which was thought to be important is actually unimportant, and *vice versa* ; in fact, the rough value of the various derivatives must be assessed before the relevance of the accuracy of any data can be judged. (Appendix B. 6.) It must always be remembered that the object of the analysis is practical—that is, that it should lead to action. Attempts at undue and unnecessary precision are to be avoided.

7. 6. *On the Use of Inequalities.* Sometimes upper or lower limits of the value of certain yields or variables are known more accurately than the actual values. In this case it is often convenient to work throughout with inequalities rather than with equations.

Whether useful conclusions are obtained by this method depends on the result of the calculations, and the nature of the practical action that can be taken. Very often practical action can be legitimately taken after proof that some quantity is larger than another, even though how much larger is not known.

To compare a proposed new tactic B with an existing tactic A, of which the actual Yield Y_A is known, assume upper limits (i.e. most favourable to B) for the relevant variables. Then if the calculated upper limit Y'_B of the yield of the new tactic is less than Y_A, tactic B is *certainly* inferior and so the relevant decision can be taken. On the other hand if $Y'_B > Y_A$, no useful conclusion is obtained without further calculation. Now assume lower limits (i.e. most unfavourable to B). If now $Y''_B > Y_A$, tactic B is certainly superior, etc.

8. Some Properties of Operations

8. 1. *An Equilibrium Theorem.* It is clear that an intelligently controlled operation of war, if repeated often enough with reasonable tactical latitude allowed to the participants, will tend to a state where the yield of the operation is a maximum, or the negative yields (losses) a minimum. Exceptions will, of course, occur for various reasons. For instance, if the tactics of the operation are restricted by too rigid orders, or if the yield of the operation is not known to the participants.

This result clearly follows from the fact that in the course of repeated operations by many different participants, most of the possible variations of tactics will be effectively explored, so that any large derivatives will eventually be discovered, and given intelligent control, improved tactics will become generally adopted. The result will be a gradual approach to a tactical state with certain maximum properties, that is, one in which what may be called the *free* tactical derivatives are nearly zero.

This theorem may be of use in attempting to detect in some complicated operation those tactical derivatives which have large values and so repay close study. These large tactical derivatives are most likely to be found under circumstances where their large value would not easily have been detected by the participants because, for instance, control has been too rigid, or because the yields have not been observable, or because the yields, though observed, have not been subject to the necessary analysis. (Appendix B. 5.) Such derivatives can be called *locked* derivatives to distinguish them from *free* derivatives.

When some condition of maximum *net* yield has been attained, it must be due to some balance having been attained between counterbalancing factors, such as increasing absolute yields and increasing absolute losses. The interpretation of certain operational situations may be considerably facilitated by such considerations. Provided a real equilibrium condition can be established, one can make useful deductions in a way that is analogous to the use of the ' virtual work ' theorem in mechanics.

8. 2. *Operational Constants and Operational Functions.* Closely related to the above considerations is the observation that often the numerical characteristics of some type of repeated operation retain a surprising constancy over a long period of time.

An example of such an approximate operational constant is the fraction of U-Boats sighted by aircraft in daylight which are attacked while still visible. More general and significant, however, than this fraction, is the distribution of times of submergence of U-Boats at the moment of attack. This operational function is also found to remain surprisingly the same over wide periods of time and place. (Appendix A. 4.)

Very often such functions are of a type that are completely incalculable from first principles, depending as they do on numerous and complicated factors such as the average fatigue of look-outs, etc.

The determination of such nearly invariant functions and constants may be a step of great importance in the analysis of certain types of operations.

The following examples are given to illustrate some of the special points discussed in the text. The figures and results quoted are not to be taken as necessarily accurate or authoritative.

APPENDIX A (DOCUMENT II.)
EXAMPLES FROM THE AIR CAMPAIGN AGAINST U-BOATS

A. 1. Consider the case of anti-U-boat operations by aircraft. The yield of the operations may be taken as the number of U-boats damaged by aircraft in a given time ; it will depend at least on the following variables :—

U-Boats :
- Number operating
- Tactics
- Defensive strength
- Offensive armament
- Geographical distribution
- State of training and morale of crews
- Efficiency of look-outs

Aircraft :
- Number and duration of sorties
- Search tactics
- Height of patrol
- Attack tactics
- Bomb load
- Accuracy of bombing
- Geographical and temporal distribution
- Performance
- Camouflage of aircraft
- Performance of radar
- State of training and fatigue of crews

Weather Conditions :
- State of the sea
- Cloud, height, and amount
- Visibility

To attempt an *a priori* solution of this problem is clearly absurd. But if past operations are studied to give actual values of the yield, reasonably accurate predictions of future operations may be possible by the variational method. Many calculations of this type are to be found in Coastal Command Operational Research Reports.

A. 2. Suppose one wishes to estimate the probable gain in numbers of sightings by the introduction of a new type of radar. Suppose that there are already in use two different types characterised by different ranges R_1 and R_2 of detection. Then give sufficient numbers of sightings by the two equipments, the ratio (dY/dR) can be obtained and so the effectiveness of the new equipment predicted.

A. 3. When insufficient experimental data to give a statistically significant answer is available, one must use a theoretical argument. For instance, for the above problem, one would assume the number of sightings to be proportional to the radar range when this is larger than the visual range, and independent of the radar range when this is less than the visual range. Thus, using the relevant statistics of the actual frequency of occurrence of different visibilities, one can calculate the required predicted gain.

A. 4. *Conditions of U-Boats at moment of attack*

An analysis of a large number of day attacks in 1941 in the N. Atlantic give the following statistics for the number of U-boats visible and having submerged for different times at the moment of attack.

TABLE I

Condition of U-Boats	P = *Percentage of all attacks.*
U-Boats visible	34 %
Submerged 15 secs.	27 %
,, 15-30 secs.	15 %
,, 30-60 secs.	12 %
,, 60 secs.	11 %

This observed operational function $P = f(t)$ where t is time of submergence at the moment of attack, was found to remain nearly unchanged throughout 1942 and was approximately the same on the Eastern seaboard of U.S.A. as in the Atlantic.

The form of this function depends on extremely complicated factors such as the distribution of the state of fatigue of the U-Boat and aircrew look-outs etc. It is clear that if U-boat look-outs were always as efficient as they can be and sometimes are, then no U-boats would ever be caught on the surface except in low visibility. Thus the actual effectiveness of much of the air campaign against U-boats depends essentially on the failure of the U-boat look-outs to be uniformly efficient.

This provides a good illustration on the one hand of the essential unpredictability from first principles of many of the most important aspects of war operations, and on the other, of the wide field for exact calculation, opened up once the essential operational functions have been experimentally determined. For by using the figures of the above table a number of precise deductions can be made.

A. 5. *Effect of Speed of Aircraft on the Fraction of Sightings that Lead to Attack on a Visible U-boat*

Assuming as a first approximation that the mutual sightings of aircraft by U-boat and *vice versa*, depend only on their mutual distance, then the increased number of attacks on visible U-boats due to the reduced time from sighting to attack due to increased aircraft speed can be deduced directly from Table I.

As a second approximation, the variation of average *distance* of reciprocal sightings with speed of aircraft, due to the finite speed of visual scanning, can be taken into account by making use of suitable laboratory or field observations.

A. 6. *Effect of Aircraft Colour on Fraction of Sightings that Lead to Attacks on Visible U-boats*

The first step is to make an *experimental* determination of the effect of change of colour on the distance at which an aircraft is likely to be picked up. Then from the figures of Table I and a knowledge of the average aircraft speed to which they referred, the required effect of camouflage can be calculated.

The detailed calculation, as made by the late E. J. Williams, is as follows :

'Let us suppose that painting a black Whitley white reduces the distance at which it will be seen by a U-boat by 20 per cent. (which is roughly the estimated effect of the change). We shall assume that it takes a U-boat 45 seconds to dive. Then a U-boat which is submerged t seconds when attacked by a black Whitley will have seen the aircraft when it was at a distance of about $(t + 45)$ v away, v being the speed of the aircraft (assuming a roughly straight approach). If now the Whitley had been white, it would have been seen at a distance of 20 per cent. less, i.e., $0{\cdot}8$ $(t + 45)$ v. Therefore the time the U-boat would have available for diving would be $0{\cdot}8$ $(t + 45)$. Therefore, if this expression were equal to 45 seconds, the U-boat would be caught just at the end of its dive. Actually $0{\cdot}8$ $(t + 45)$ is equal to 45 when $t = 12$ seconds. The answer, therefore, is that a white Whitley will catch as many U-boats on the surface as a black Whitley, plus those which, with the black Whitley, will have been submerged 12 seconds. Reference to Table I shows that this would correspond to an increase of the order of 30 per cent. in the number of U-boats caught while still partly visible. The improved camouflage would also increase the total number of sightings.'

A. 7. *Quantitative Estimate of the Value of a Good Visual Look-out from A/S aircraft*

For certain aircraft on A/S operations, it was found unexpectedly that the number of U-boats seen on the port side was just double the number seen to starboard. This is undoubtedly due to the fact that the pilot normally scans his own side (the port side), and that he has little else to do, since the aircraft is flown by automatic pilot. On the other hand, the second pilot responsible for the starboard side has various duties and distractions.

It can thus be deduced that if the look-out to starboard had been as good as that to port the number of U-boats sighted would have been increased by 33 per cent. By this simple analysis, based on an unexpected statistical result, a quantitative estimate can be given of the probable gain by improved look-out organisation.

This example shows the value of exploratory investigations even in seemingly unprofitable fields. Any such discovery, say, of an unexpected asymmetry as above, may serve to give a value of some desired differential co-efficient.

A. 8. *Asymmetry of Sinkings in Convoy*

Another example of the value of exploratory investigation is the discovery that, over a certain period, half again as many ships were sunk on the starboard side of the N. Atlantic convoys in 1942 as on the port side. This quite unexpected, and previously undetected asymmetry, could be used to give immediate operational advantage by the adoption of suitable escort tactics. (Since no explanation was ever found of this effect, it was finally concluded that it might be due to a statistical fluctuation and so no action was recommended.)

APPENDIX B (Document II.)

EXAMPLES FROM THE CONVOY BATTLE

B. 1. *Variation of Loss of Ships with Various Parameters*

The first step in the analysis is to break down the statistics of loss in such a way as to give their variation with the main variables of immediate interest. These variables are :—

Number of escorts
Size of convoy
Speed of convoy
Amount of air cover.

For instance, in the N. Atlantic convoys in 1941 and 1942, such a breakdown gave the following results :—

Number of Escorts

An increase of number of escort vessels from 6 to 9 led to a reduction of losses by about 25 per cent.

Size of Convoy

An increase of size from an average of 32 to 54, was associated with a decrease of fractional losses (*i.e.* ships sunk ÷ ships sailed) from 2·5 per cent. to 1·1 per cent., i.e., a reduction of losses by 56 per cent.

Speed of Convoy

An increase of speed from 7 to 9 knots was associated with a decrease of fractional losses from 2·1 per cent. to 1·2 per cent., i.e., a reduction of losses by 43 per cent. The analysis also showed that this effect of speed was dependent on the existence of the air cover.

Air Cover

Air cover of 8 hours per day in the last half of 1942 was associated with a reduction of losses by 64 per cent.

B. 2. *Derivative Form of these Results*

Since in each of these derivations it was verified that the average value of the other variables was about constant, the four results represent in effect four partial derivatives.

Making the reasonable assumption that these derivatives are causally significant, one can use them to calculate the relative value in saving shipping in 1941–1942 of the four factors, numbers of escorts, size of convoy, speed and air cover.

B. 3. *Comparison of Derivatives*

Thus it follows immediately that the number of escorts would have to be increased from 6 to 14 to make a convoy without the above amount of air cover as safe as one with air cover. Such an extrapolation, from 6 to 14 escorts, must be considered a rather large extrapolation, and so be subject to a large probable error. The same consideration applies to the following comparisons.

Similarly the number of escorts would have to be increased from 6 to 10 to make the average slow convoy as safe as the average fast convoy.

Again the number of escorts would have to be increased from 6 to 11 to reduce the percentage loss of ships in small convoys of average size 32 to the losses in larger convoys of average size 54.

The above calculations enable the rough profitability of various possible changes to be compared, and so a basis can be laid for costing such operations of war. It will be noticed that it is the *marginal* profitability, i.e., the gain resulting from small increases in some factor, that is given directly by such analysis.

B. 5. *Comments on the Above Results*

Though the value of escorts, speed and air cover has always been appreciated, till this analysis was made there appears to have been little *quantitative* knowledge of their value. The very high value of speed and air cover, under at any rate the special condition of the N. Atlantic convoys, was somewhat of a surprise.

It is interesting to note that, previous to this analysis, even the qualitative advantage of large convoys (i.e. a few large convoys in comparison with more small convoys) had not been generally recognised. In fact the general view had been that large convoys were more dangerous than small.

B. 6. *Marginal Value of very Long Range Aircraft for Convoy Protection*

For the case quoted in B. 1, it can be deduced that every three sorties of a very long range aircraft employed on these duties saved one merchant vessel. Allowing 40 sorties per aircraft expended, this gives 13 merchant vessels saved for each aircraft expended on this type of operation. Even if this estimate were, say, over ten times too high, so that each aircraft expended saved only one ship, the operation of giving an escort to convoys in mid-Atlantic would be extremely profitable. This illustrates the moral of the section on the use of rough data.

This example also illustrates the danger of undue extrapolation. For it would be clearly rash to assume that the relation between aircraft losses on the convoy and ships saved is a linear function, i.e. that the differential coefficient d (ships saved) $/d$ (aircraft hours) is constant. To estimate what would be the saving of ships by a doubled air effort, i.e. 16 hours per day, would clearly need a theoretical investigation of the mechanism of the saving so as to establish the *form* of the function relating the protection afforded to the amount of the air cover.

B. 7. *A Quantitative Estimate of the Importance of Training, Leadership and Efficiency of Escort Groups in the Convoy Battle*

An order of merit for the efficiency of Convoy Escort Groups was obtained by evaluating for each group the total number of ships lost in convoys escorted by the group together with the number of days in which U-boats were in contact with the convoys. By division the number of ships lost per U-boat day was obtained for each group, and so the groups were arranged in an order of merit of efficiency. The groups in the upper

and lower half of the list were designated the first and second class groups respectively, and the average losses calculated for the two classes, with the following results :—

	Ships lost	*U-boat days*	*Ships lost per U-boat day*
1st class	20	181	0·11
2nd class	78	175	0·45
Total	98	356	0·27

If the second class groups had been on the average as efficient as the first class groups, the total number of ships which would have been lost is $356 \times 0{\cdot}11 = 38$ instead of the actual 98, that is a saving of 60 ships, i.e. a saving of 61 per cent. of the actual losses.

This estimate is conservative, since the more efficient groups undoubtedly succeed in reducing by tactical evasion the number of days U-boats are in contact with a convoy.

This example shows how it is possible to deal quantitatively with differentials with regard to such ' non-quantitative ' variables as training, etc. Some of the observed variations between the different groups may, of course, have been statistical in origin, and so further data and analysis would be needed to establish the real difference in efficiency.

APPENDIX C (Document II.)

EXAMPLES FROM BOMBING OFFENSIVE

In early 1942, it was important to attempt to estimate the effects of the British Bombing Campaign on German war production. To do this it was necessary to use the data about the German attacks on Britain in 1940/41 as a basis. These showed that, roughly speaking, the loss of industrial production, material damage to buildings and civilian casualties, were all, on the average, about proportional to the weight of explosives dropped. As a first step, therefore, to calculating the effect on production, it was useful to calculate the probable civilian casualties in Germany due to our bombing effects. This calculation is a useful exercise, as it gives a simple numerical answer which should be compared, after the war, with the actual figures.

C. 1. To estimate from first principles, say, the number of civilian casualties likely to be produced by a given bombing effort, it would be necessary to make numerical assumptions of at least the following factors.

Lethal efficacy of different types of bombs and fuzing.

Distribution of bombs about the target.

Types of housing attacked and vulnerability to different type of bombs.

Habits of population, i.e. how many in streets, houses and shelters.

Such an investigation even if possible, would be laborious and the result would be uncertain.

A quicker and, in general, more reliable method is to use the known results of one bombing offensive where the casualties are known to predict the effect of another offensive where the casualties are not known. In the calculation allowance is made for the differences between the two cases of as many factors as possible.

C. 2. As an example, an estimate can be made of the effects of the British bombing offensive against Germany in 1941, using the known results of the German bombing offensive against Great Britain in 1940.

In the ten months from August, 1940, to June, 1941, the total weight of bombs dropped on the United Kingdom by the enemy was about 50,000 tons, that is, at the average rate of 5,000 tons per month. The number of persons killed was 40,000, or an average of 4,000 per month, giving 0·8 killed per ton of bombs.

Static detonation trials showed that the British G.P. bombs then in use were about half as effective as the German light-cased bombs of the same weight. Hence, these bombs should produce only 0·4 killed per ton, when dropped under the same conditions. Our bombers had further to go to their targets, the enemy towns are less easy to find, and are smaller, and no radio aids were then available. One must therefore assume that the fraction of bombs falling in built-up areas in Germany was not more than half of the fraction of German bombs falling on built-up areas in Great Britain. Hence, we should expect about 0·2 killed per ton of bombs dropped. During 1941 an average of about 2,000 tons of bombs were dropped on Germany per month. The expected number of killed is therefore $2{,}000 \times 0{\cdot}2 = 400$ per month.

The calculation above consists essentially in estimating $d(\text{casualties})/d(\text{type of bomb})$ and $d(\text{navigational errors})/d(\text{type of operation})$.

When the actual figures become available through intelligence sources or at the end of the war, it will be interesting to see how far this estimate is in error ; and if it is seriously in error, to find which other differential coefficients should have been taken into account.

The calculation above could be refined to take any other derivatives into account, e.g. $d(\text{navigational errors})/d(\text{meteorological information})$. In a similar way the difference

in building technique, and shelter policy could be taken into account, given sufficient information.

The above problem illustrates how any answer obtained by the variational method can be considered as an approximation to be improved successively as more information about other derivatives becomes available. It also illustrates the method of the derivation of the yield of one operation from that of another, by estimation of a number of multiplying factors appropriate to the various variables under consideration.

NOTE (1948).

From the United States Strategic Bombing Survey we find that the average monthly numbers of German civilians killed by bombers were roughly 200 in 1941 and 400 in 1942.

APPENDIX D (DOCUMENT II.)
AIRCRAFT IN WARFARE (1916)
BY F. W. LANCHESTER

A SIMPLIFIED treatment of Lanchester's Theorem is given below. Suppose A units of one force of hitting power α are engaged with B units of an enemy of hitting power β. Suppose further that the engagement is of such a kind that the fire power of force A is directed equally against all units of B and *vice versa*; then the rate of loss of the two forces is given by

$$\frac{dA}{dt} = -k\,\beta\,B \text{ and } \frac{dB}{dt} = -k\,\alpha\,A$$

where k is a constant.

The strength of the two forces is defined as equal when their fractional losses are equal, i.e. when

$$\frac{1}{A}\frac{dA}{dt} = \frac{1}{B}\frac{dB}{dt}$$

Using the above relation we get

$$\alpha\,A^2 = \beta\,B^2$$

Thus the *strength* of a force, on these assumptions, is proportional to the fire power of a unit multiplied by the *square* of the number of units.

Lanchester develops this interesting theorem with great ingenuity and shows clearly its limitations. Its possible application to historic battles, in particular to Trafalgar, is discussed in a very interesting manner.

Such *a priori* investigations as this are of very little use for handling a complicated event like, say, a mass U-boat battle against a convoy. They are of some use sometimes in handling selected parts of such battles, for instance, to calculate the chance of a U-boat penetrating undetected an escort screen of a given number of escort vessels under given weather conditions. Such *a priori* calculations are nearly always useful and necessary to study the performance of the actual weapons, for example, to calculate the chance of killing a U-boat, with, say, a 14 pattern depth charge attack, under certain assumed conditions of plan and depth errors.

SUPPLY AND UTILISATION OF COAL

> 'Coal in truth stands not beside but entirely above all other commodities. It is the material source of the energy of the country—the universal aid—the factor in everything we do. With coal almost any feat is possible or easy; without it we are thrown back into the laborious poverty of early times'
>
> W. S. Jevons in *The Coal Question*, 1865.

AT the meeting of the British Association in Dundee in 1947, the first year of national ownership of the coal mines, four of the thirteen Sections included in their programmes discussions and papers on various aspects of coal. In the Geology Section the President delivered his address on Geology in the Development of the Coalfields. This was followed by a group of nine papers on The Future of Coal Supplies. The Physics Section arranged a symposium in which seven speakers discussed Coal as a Source of Heat and Power; the Engineering Section received a paper on the mechanisation of collieries; and in a discussion on Man and the Machine, which was arranged by the Sections of Physiology, Anthropology and Psychology, attention was given to the working conditions of the miner. The following is a synoptic record of those proceedings.

Introduction

In opening the Physics Section's symposium on Coal as a Source of Heat and Power, Sir Edward Appleton said :

In spite of our experience during the fuel crisis of the early months of this year (1947) I am not sure that even now do we all fully realise the extent to which we have been dependent on our supplies of coal from our underground reserves in building up our position as one of the foremost industrial nations of the world and in raising the standard of life of our own people.

It is worth looking back into our history for a moment, before we start to look forward. There was a time, round about the year 1700, when our country was largely an agricultural one and when we had a population of only 6 to 7 million people. In those days our consumption of coal was about ½ a ton per person per annum.

During the eighteenth century, when the first signs of industrialization became evident, the amount of coal consumed per person per annum began to increase so that by 1800, with a population of about 10 million people we had increased our consumption to 1 to 1½ tons per person per annum.

It was after that that real industrial development started, based on the energy derived from coal. We were fortunate in having large reserves of coal of good quality and that, together with the inventive genius and enterprise of our engineers and industrialists of the nineteenth century gave us a good lead over other countries.

We then advanced so rapidly that by 1900 we had an annual output of 220 million tons and were consuming approximately 6 tons of coal per person per annum. In other words, while our population increased during the nineteenth century four-fold, our coal production increased twenty-fold.

The record production was reached in 1913 when we produced 287 million tons. Most of that coal was used for domestic and industrial purposes, but we had in that year a surplus of 70 million tons available for export.

In these days of shortage of labour, it is instructive to calculate how much energy we can get from coal to supplement our own manual work. When we burn or gasify one ton of coal and use the energy through steam or in a gas engine, or in some other way, even with an efficiency of only 20 per cent., we get useful energy equivalent to more than 2,000 horse-power hours. To get the same amount of useful energy from manual labour would require 4,000 labourers working hard for 8 hours. An annual production of 200 million tons of coal, if used with an efficiency of 20 per cent. for generating power, can thus provide us with a service equal to 3,000 million men doing hard manual work for 40 or 50 hours every week for a whole year, or the labour equivalent of 70 men for every member of the population. In other words, each one of us has the equivalent of 70 servants working hard for us—and servants not drawing on our food supplies. This indicates why our standard of living is largely dependent on our having ample supplies of fuel and using these supplies efficiently.

Before the 1914–18 war, coal was plentiful, selling competition was keen, and coal of excellent quality, as measured by its calorific value and the proportion of ash it contained, could be obtained at a low price. The price was perhaps too low, with the result that coal was used wastefully, and much useful material was discarded with the refuse in the colliery dumps.

It required the first World War to bring us up sharply against the question of fuel economy. Production during that war declined (from 287 million tons in 1913 to 230 million tons in 1918) and, because demands were high, there was a move in the direction of using fuel less wastefully. It was largely as a result of the experience during the 1914–18 war that the Government established the Fuel Research organization of the Department of Scientific and Industrial Research, which began active experimental work in 1919 at the Research Station at Greenwich and later set up the Coal Survey with a laboratory in every important coalfield.

Between the two great wars production remained at an average of about 230 million tons though there was always an average export of about 40 million tons. During the recent war and since, output has declined until it is less than 200 million tons, while demand has increased and is increasing. Although the fuel situation during the last few years has been admittedly difficult, it is certain that it would have been still more difficult without the increased efficiency which has already been achieved, especially in industry.

Whatever the reasons for this decline in output, it is certainly not because of shortage of workable coal underground. The investigations of the Fuel Research Coal Survey, in co-operation with the Geological Survey and the industry have shown that we have sufficient workable coal of all the main types to provide 250 million tons a year for at least 100 years and probably for 200 years and possibly longer. Still, 200 years is not long in the lifetime of a nation ; and even if output is later increased it will still be important to strive for greater efficiency in the use of coal.

But with the fall in coal production during the last few years, there has also been a reduction in average quality. This has been inevitable with the need to conserve coal and reduce the quantity of combustible material discarded at the collieries. There are other factors which have contributed to this reduction in quality. These factors include an extension in machine cutting of coal, the recovery of low grade fuel previously rejected, and unavoidable delay in the maintenance and extension of coal cleaning plant. With all the problems of shortage of coal and transport, it is not always possible to ensure uniformity of quality of supply to consumers ; and this does not simplify the problem of using the coal more efficiently. There is no doubt, however, that the National Coal Board are aware of all the difficulties and problems, and are working hard in the direction of making improvements ; but the task is heavy and will take time.

Geology in the Development of the Coalfields

In his Presidential Address to the Geology Section Dr. M. Macgregor discussed how geology and geologists could best assist in the development of our coal resources and in their most effective and economic use. He said this was not an academic or debatable issue ; it was an urgent and vital one. It was certain that the coal industry was under a great debt to geology : it was equally certain that the debt might well have been much greater. The fault for this could not be laid wholly at the door of geologists, but it would be their fault if they did not grasp the opportunities now offered in the new era, opportunities not only for service to the country but also for the advancement of geology.

To play their full part in the development of the coalfields, geologists must be prepared to render assistance along three main lines :—

(1) They must be ready to advise on geological difficulties and problems as they arise in the actual working of the coals, and to make suggestions for overcoming them.

(2) They must be ready to advise on development of plans involving an extension of existing workings into fresh ground.

(3) They must be ready to apply the results of detailed work on the lithology, sequences, structure and palaeontology of the explored or partly explored fields to the investigation of new ground or concealed areas of potential value.

These three types of investigation must be regarded as stages of a continuous and continuing advisory scheme.

Dr. Macgregor enumerated gaps in existing knowledge to illustrate the wide scope obtaining for continuous research on carboniferous rocks from both the scientific and the economic points of view and said that first-hand knowledge of coalfield developments, time and opportunity to study and assess the difficulties and problems that arise, and close and continuous liaison with the mining industry were all necessary if geology was to take its right place in the forefront of our economic life. What was required was a team trained in coalfield work to form an integral part of the Geological Survey service and to be assigned the task of carrying on and extending the work which the Survey, with its limited staff and multifarious duties, had not, so far, been able to complete.

The Future of Coal Supplies

Prof. H. G. A. Hickling said that the future of coal in this country depended partly on actual resources, but still more on their most effective uses. Total supplies were unlikely to approach exhaustion within any period for which it was now possible to plan. Particular varieties, however, were more limited as regards known reserves, especially the first-class coking coals, anthracites and semi-anthracites, and exceptionally low-ash coals. The most effective use depended upon growing knowledge of the constitution and properties of the many varieties, of the manner in which they had originated and the way in which this was related to their existing distribution.

Most coals consist predominantly of relatively large pieces of fossilised plant tissue (vitrain and fusain) interspersed with varying proportions of finely divided more resistent plant residues which form dull bands or partings (durain). The constitution of the durain varies greatly, and this variation plays a large part in the determination of the properties of the different coals.

In a still greater degree the properties of coals depend on the extent of alteration, or maturation, which the coal-substance has attained under the influence of geological conditions. The general key to the cause of this change is to be found in the fact that in every locality the deeper coals are more altered than those which lie above them, though the original differences of constitution commonly obscure this relation over moderate differences of depth.

The same relation makes possible an understanding of the variation of the properties of coals from different fields and from different portions of the same field. It carries the

hopeful corollary that as we are compelled to mine deeper coal this must be accompanied by a small but definite increase in average quality. This circumstance is likely to prove of material consequence, especially in relation to the future resources of coking coals.

Evidence of Coal Development

Dr. A. C. Seyler described recent investigations into the manner of change of the main constituents (vitrains) of normal coals. These constituents may be classified into three groups (i) perhydrous (rich in hydrogen) including *exinites*, derived from spores and cuticle, and *resinites* derived from resinous substances (ii) ortho-hydrous (moderate hydrogen content) comprising components of bright coals of various ranks, (iii) subhydrous (low hydrogen content) including *fusinite*, derived from lignified tissue which has lost part of its hydrogen.

Dr. Seyler distinguished the various components by their optical properties observed under a microscope fitted with a Berek photometer, and observed the change in the main constituents as shown by their increase of reflecting power as the coal advanced in rank. He found that the reflecting power changed abruptly through a series of nine steps terminating with *fusinite*, the highest component yet found in coal. Thus, unexpectedly, the changes in the constituents of coal appear to be discontinuous. As the rank of the seam advances to a critical point each component present (except fusinite which does not alter) changes its reflecting power one step upwards in this series. Stepwise changes have been observed in vitrinites which have been subjected to alteration by contact with volcanic intrusions ; the same steps have been observed in coal carbonised at atmospheric pressure at certain temperatures, and, still more remarkable, when wood or other lignified tissue is carbonised, the 'chars' are members of the same series. It is concluded that heat, under certain conditions, is capable of having caused the various stages in the development of normal coals.

Physical and Chemical Survey of Coal Resources

The results of twenty-five years of survey work by the Fuel Research Organisation of the Department of Scientific and Industrial Research were described by Dr. A. C. Monkhouse.

There exist to-day nine coal survey laboratories situated in or near the principal coalfields, at Glasgow, Newcastle-upon-Tyne, Chester, Manchester, Leeds, Sheffield, Birmingham, Nottingham and Cardiff, in addition to the Fuel Research Station at Greenwich. The survey work consists of detailed examination of the coal seams as they occur underground, together with an examination of the commercial grades sold by the collieries. From the chemical and physical analysis of coal it is possible to obtain considerable information on the properties of coal. Where it is used for a specific purpose, such as gas-making, large scale experiments in addition have been undertaken on a number of coals as a correlation with laboratory work. The results of the Survey have been published in some 60 reports and the work continues. There is now available more information on the types of coal in the various seams in this country than there is about the coals in any other country in the world.

The information obtained has proved invaluable in the allocation of coals and much use was made of it during the war and post-war years when normal supplies were interrupted and consumers had to take coals from other areas. In many cases it was possible to match the coal from one district with that of another.

When, under the Coal Act of 1938, the ownership of unworked coal was transferred to the nation as at 1st July, 1942, opportunity was taken to assess the types, as well as the quantities of coal scheduled to be worked in Great Britain in the next 100 years (being the normal 'valuation' period for the assessment of compensation to owners). The coals were divided into six main groups—(1) anthracite, (2) low and medium-volatile steam coals, (3) medium-volatile coking coals, (4) high-volatile strongly caking and medium caking coals, i.e. the coking-gas and gas coals, (5) high-volatile, weakly caking coals, (6) high-volatile very weakly caking and non-caking coals. The analysis of the figures obtained by this classification showed the satisfactory result that there is no marked tendency in the country as a whole for any of these groups to tail off more quickly than the others so that whatever may be the position after 100 years, none of these broad types will be exhausted within that period.

The information obtained by this qualitative-quantitative survey is of assistance in planning to make the best use of our coals, and is the first appraisal of our resources in terms of types of coal. A more complete picture will be obtained as more information about total reserves becomes available from the work of the Geological Survey.

The original aim of the Survey, to obtain as complete information as possible of the chemical and physical properties of coal, led naturally to an extension of the work to the problems of production and to the problems of the users of coal. For example, the

Survey assisted both in the prospecting of sites and the taking of samples for control and development of opencast coal mining. The avoidance of heating and firing of coal when stored in large heaps has been the subject of study, and advice has been given on methods of storage, supervision and inspection of the heaps and on methods of dealing with fires. Experiments have been undertaken in covering the heaps with a coating of road tar to prevent ingress of air and subsequent heating. There has been an increasing demand for cleaned small coal in graded sizes. This gave rise to problems connected with the breaking of coal without the undue production of small sizes and to investigations into the methods of coal cleaning.

During the war an alternative fuel to petrol was required for use in road vehicles. In conjunction with other organisations and firms, producer gas units were developed to use anthracite or other suitable solid fuel. Another requirement in which the Survey helped was the finding of types of coal which when treated either in lump form or as briquetted blends by the appropriate technique, would be likely to yield active carbons.

The Ministry of Supply endeavoured during the war to increase the production of indigenous sources of sulphur for the manufacture of sulphuric acid. One possible source was the pyrites present in coals. Waste material at collieries was investigated from which pyrites might be recovered. As a result of these investigations recovery plants were erected and some 25,000 tons of pyrites fines were recovered per annum, in addition to about 10,000 tons per annum of lump pyrites, of which about 5,000 tons was used for smelting. The sulphuric acid produced from coal pyrites per annum amounted to about 33,000 tons in terms of 100 per cent. sulphuric acid.

The Coal Survey is now being transferred to the National Coal Board and the maximum use will be made of the Survey to provide information on the planning and development of our coal resources and the proper allocation of coals, at the same time extending existing knowledge.

Possible Extensions to the Midlands Coalfields

As an indication of the problems facing geologists and mining engineers in their endeavours to discover new supplies of coal to replace the dwindling reserves in already proved areas, Dr. G. H. Mitchell described the position in the Midlands Coalfields which extend from Wellington in Shropshire to Leicester and include the fields of Coalbrookdale, Wyre Forest, South Staffordshire, Warwickshire, South Derbyshire and Leicestershire.

The Midlands Coalfields produce a considerable output of house and steam coal, contributing greatly to the prosperity of the many industries and the large population of Midland England, as well as sending large supplies to London and the south. It is generally agreed that, within the lifetime of the next generation, a steady decline in output of the present known areas will set in as the seams become exhausted. Indeed, unless new fields are discovered, the highergrade coals will be greatly reduced longbefore that time and the process of their replacement by inferior coals, already considerably advanced, will be accelerated.

The successions of coals within individual coalfields are in almost all cases accurately known and reliable estimates of reserves can be computed. Consequently, exploration within the present known areas is a small part of the problem. Moreover a fairly accurate correlation from field to field by marine beds and mussel bands is available to assist in boring. Of prime importance is the proving of the extensions of the coalfields. These extensions are now almost entirely under cover of newer formations, either beneath the unconformable Upper Coal Measures or the succeeding New Red Sandstone, itself unconformable on the Coal Measures. The search for new coalfields depends on the estimation of the geological conditions, structural and depositional, and the proof of such estimates depends on a programme of boring much more extensive than any yet undertaken in the district.

Dr. Mitchell described some of the difficulties involved in prospecting for extensions. For example, as proving is carried eastward in one area (Coalbrookdale) the cover of New Red Sandstone will increase to 2,000 feet thick and, east and west of the S. Staffordshire field, borings of 2,000 to 3,000 feet through similar rocks may be necessary. In South Derbyshire the principal extension was likely to be to the west where borings of 3,000 feet or more would be required.

In Dr. Mitchell's view it was urgently necessary to prove new coalfields before the present reserves in this area were exhausted, but coal would be progressively more difficult to find and deeper to work. New collieries were likely to lie away from the present areas of population in country now pastoral and devoid of the means of transport and other facilities. The movement, however, should be gradual, allowing time to effect the necessary changes.

Prospects of Discovering New Coalfields in the United Kingdom

Dr. G. M. Lees read a paper prepared by himself and Mr. N. L. Falcon, on the prospects of finding new reserves of coal as indicated by evidence obtained during the search for oilfields.

The discovery of oilfields in Millstone Grit Sandstones in Nottinghamshire has led to an intensive search for similar geological conditions elsewhere in England ; and, as one of these conditions is that the oil sands should have a sufficient cover of Coal Measure shales to prevent escape of the oil, it follows that the search for new oilfields may incidentally discover new coalfields and has, in fact, already done so.

The method of search begins with speculative geological thinking and drawing deductions as favourable as is possible from the limited facts. Certain areas are thus selected as having sufficient promise to justify geophysical exploration, the areas concerned being exclusively covered by unconformable rocks, and so not amenable to surface geological treatment. The first surveys are made by gravity and magnetic instruments which may give a broad and generalised picture of underground structure. Certain areas of apparent promise may then be selected for seismic survey and finally, if the geophysical results seem favourable, selected locations are drilled.

So far an extensive coalfield has been discovered by borings in Central Lincolnshire, but although the seams are too deep for present-day exploitation (4,000 to 5,000 ft.) there is a good prospect that the Measures will rise to lesser depths in the vicinity of the Wash. A considerable extension of the Nottingham coalfield has been proved to the south-east of Nottingham city, and may even extend to the Wash. The possibility of Coal Measures in North Norfolk has been disproved by a boring at North Creake.

Exploration is proceeding in extensive areas in the Midlands and South-central England, as a result of which new discovery of coalfields is thought possible :—

(1) In the vicinity and to the west and south-west of Market Drayton in Shropshire, and between there and Burton-on-Trent : seismic surveys have been finished, to be followed by exploratory borings.

(2) In three areas where gravity and magnetic surveys have been made yielding results which are under analysis, i.e. in Wiltshire as an eastern continuation of the Somerset Coalfield, or perhaps as an independent coalfield ; in the Cotswold country of Gloucestershire, and perhaps in Southern Worcestershire ; in certain areas in Oxfordshire, perhaps between Oxford and Reading.

(3) In Eastern Essex, where work has not yet begun.

In addition to those areas, there are many possibilities of extensions of known coalfields and also of possible other fields in areas outside the scope of the exploration programme reviewed.

In conclusion Dr. Lees said that such incidental discoveries of new coal reserves were subsidiary to the search for oil, which was sponsored by private enterprise and which might have to be abandoned at any time. He emphasised the need for a national effort to prove and develop new sources of coal supplies.

Coal as a Chemical Raw Material

In the last paper of the session arranged by the Geology Section, Dr. R. Holroyd dealt with coal as a raw material in the chemical industry. In addition to being a major consumer of coal for fuel purposes, the British chemical industry is largely dependent for its raw materials on the availability of coking coal. This dependence takes two forms : firstly, the chemical industry consumes all the phenol, cresol, naphthalene and anthracene extractable from the two million tons of coal tar per year obtained by coal carbonisation, as well as benzene, toluene, xylene, etc., equivalent to about a quarter of the U.K. production of crude benzole. Secondly, roughly one million tons per year of coke with high melting-point ash is used for production of water-gas or hydrogen for chemical synthesis. The direct use of coal as a chemical raw material is negligible.

Coal carbonisation as a method of production of aromatic chemical raw materials suffers from the disadvantage that the yield of these products is only about 1·5 per cent. of the coal. It follows that the extent of their production is inevitably dictated by the demand for the main products of carbonisation—coke and gas. In the past the ' natural ' production of coal carbonisation by-products has sufficed for the chemical industry, but now the anticipated demand for many of them greatly exceeds the potential supply. The chemical industry has therefore had to investigate other more direct routes to these raw materials. Considerable progress has been made in the field of petroleum oil cracking plants. It would therefore seem that, although the chemical industry will continue to provide an outlet for coal carbonisation by-product chemicals to the extent that they can be produced

economically, it will in the future be far less dependent on them than has hitherto been the case.

In the field of water-gas or hydrogen production the current high cost of coal and coke has focussed attention on the efficiency of existing processes and encouraged research on new processes. It is highly probably that new continuous processes based on coal or coke will be introduced in the near future. These may follow the German developments using oxygen or may incorporate the ' fluid solid ' technique disclosed in recent American and British patents.

In either case the immediate objective will be improved efficiency and reduction of operating costs, although there would be the secondary advantage, which might in the long run be most important, that lower quality coal or coke could be employed. Thus, although the demand for ' synthetic gas ' (carbon monoxide and hydrogen, or hydrogen itself) is likely to increase considerably it is probable that dependence on special quality coal will be less in the future than at present.

To sum up, it would appear that the chemical industry is unlikely to impose highly specialised demands on the coal industry. What it required in the future, in common with other industries, is an adequate supply of coal mainly for fuel purposes at a reasonable price.

Working Conditions in the Mines

In a discussion on Man and the Machine attention was drawn by physiologists, psychologists and physical anthropologists to the failure of industry, including mining, to apply existing knowledge for the improvement in working conditions. Contributing to this discussion a paper on industrial health, Professor R. E. Browne referred to mining as the industry which demonstrates *par excellence* the failure of the mechanical environment to fit the man. Coal mining offers the worst physical, physiological and psychological conditions in the whole of industry, conditions which produce such complicated effects upon the miner that his health and his work both suffer. Of the several deadly sins of mining the worst is darkness. This causes a specific eye disease, miner's nystagmus, of which there are approximately 2,000 cases annually in the United Kingdom. It usually carried with it a psychological breakdown of the miner's personality and it costs about £1,000,000 a year. Darkness also makes a massive contribution to the large number of accidents in mines. In the period 1943, 4 and 5 there was an average of 227 reportable accidents per 1,000 men each year as compared with only 55 per 1,000 in the rest of industry. Another serious source of bad health in miners is dust which causes lung diseases from which tens of thousands of miners are now suffering. Many of the defects of underground work can and should be overcome by study and application of facts already well known to be applicable to above-ground industries. For example, it is well known that work-people in factories need at least 10 foot candles in which to work while below ground there is a different and somewhat mediæval convention that a man can work efficiently in 0·02 of a foot candle or less.

The Mechanisation of Collieries

In a paper read to the Engineering Section, Mr. Forrest R. Anderson discussed the mechanisation of coal getting operations, with special reference to coal cutting machinery. The problem that arises in the mechanisation of coal getting is to find a way whereby the coal may be broken out from the seam and filled away with the minimum demands on human labour while keeping the working places safe for continuous day by day operation. The problem involves both suitable machines and suitable mining methods. The two basic methods are the longwall system and the room-and-pillar system.

In the longwall system of mining a coal face is opened up in a straight line extending for 100 or 200 yards. This face of coal is worked forward by removing successive slices, making perhaps a 5 feet advance each time. The coal is filled on to a face conveyor, carried to the roadway at one end of the face and discharged into a roadway conveyor and thence into the tubs or mine wagons to the shaft.

In room-and-pillar working the seam is exploited by driving a series of rooms or tunnels in straight lines and at right angles to each other in the seam itself, so as to leave a succession of square or rectangular pillars of coal. The rooms may be 5 yards wide and the pillars 20 or 30 yards square, but these sizes vary greatly according to conditions.

In early British mining practice, the room-and-pillar system of working was widely adopted, but to-day the longwall system is by far the more generally employed. This has been influenced by the necessity of working thinner seams and seams at considerable depths. Consequently the machinery developed in Britain has been largely for longwall use. In America the room-and-pillar system is employed almost exclusively, probably because large virgin areas in relatively thick seams and at comparatively shallow depths are still being worked.

A great advantage of the room-and-pillar system is that it does not involve so much

stone work in the making of roadways in the working area as is required with longwall work. A higher proportion of the labour can therefore be employed on productive coal-getting operations. It has the advantage also that it is not tied to such a rigid cycle of working as in longwall practice, where usually a three-shift system is adopted and a turnover effected in 24 hours, each shift completing a particular phase of the work. On the other hand, the room-and-pillar system is best adapted for working the thicker seams at the shallower depths, and this is one reason why its application is considerably restricted in Great Britain.

A patent for a mechanical coal cutter was taken out in 1760, but mechanical cutting in this country has developed only within the last 50 years or so. Starting from practically zero at the beginning of the century it developed slowly at first and later at an increasing rate till some 70 per cent. of the coal mined in Britain is machine cut. Although introduced at a later date, mechanical conveying has also developed to a stage where 70 per cent. of our coal is conveyed at the face.

Mr. Anderson described the main types of coal cutting and power loading machinery. Whereas in America 50 per cent. of the coal cut is power loaded, only some 3 per cent. is thus loaded in Britain. Though power loading is only in its infancy in this country, more machines will be established as the relatively more difficult mining conditions can be adjusted.

Consumption of Coal in Great Britain

Sir Edward Appleton's opening remarks in the Physics Section's session have been quoted above. He went on to consider for what purposes the coal retained for home consumption had been mainly used and with what efficiencies. During the period 1936–1938 the total annual amount of coal consumed at home, in round figures, was :—

	Millions of Tons.
Domestic, including miners' coal	50
Gas Works	19
Coke Ovens	20
Electricity Stations	14
Railways	15
Collieries	12
Miscellaneous industrial uses .	52
Total, say	180

Since 1938, the major change was an increase from 14 to 23 million tons in the consumption by electricity generating stations. As regards domestic consumption there should be added about 10 million tons to allow for the coal used in producing gas, coke and electricity ; thus the direct and indirect consumption for domestic purposes was 60 million tons or one third of the total.

On the whole, the efficiency in using coal to generate heat and power was low. With the traditional open fire only one fifth of the heat value of coal served a useful purpose. Efficiency could be at least doubled by the use of modern closed and openable stoves. Furthermore, if supplies of bituminous coal could be replaced by less smoking coals and by cokes, higher efficiency could be obtained and pollution of the atmosphere would be greatly reduced. With large central boilers and central heating in large buildings, efficiency is higher but skilful supervision and operation is necessary to prevent waste. Attention is being given to the possibilities of district heating systems and to the possibilities of the heat pump as a means of upgrading heat.

In the generation of electricity at power stations, the average quantity of coal used to produce one unit of electricity was 3·4 lb. in 1921. By 1938 it was reduced to 1·4 lb. but even with this improvement the average efficiency of generation and distribution of electricity is no more than 20 per cent. on the energy value of the coal. The highest efficiency obtained at any one power station under steady conditions of load is about 35 per cent., with the consumption of 0·8 lb. of coal for each unit generated. With an improvement in coal supplies and with steadier conditions of load, therefore, a gradual increase in overall efficiency to between 25 and 30 per cent. can be expected. This is nearing the limit with the present systems of steam turbines for electricity generation and is dependent on raising steam in boilers with the high efficiency of about 80 per cent.

The carbonization processes at modern coke ovens and gas works for making coke and gas are highly efficient—from 70 to 80 per cent.—but unnecessary losses frequently occur in the use of the coke and gas.

Appliances which use coal and coke with the lowest efficiencies include railway locomotives and high-temperature furnaces for metal melting. Unless research leads to a considerable improvement in the use of coal on locomotives, there is certain to be an acceleration in a change over to oil in place of coal.

Though there are now several research organizations engaged on fuel problems, there is plenty of work ahead for all of them—and work of first importance to British industry and the community generally. If this work is neglected and if production of

coal for heat and power is not improved, there is little hope of recovering our position in world industry and of maintaining and increasing our standard of living.

The Combustion of Coal

Prof. H. L. Riley said that the present world consumption of coal was probably of the order of 1,200 million tons per annum, from which roughly 70 per cent. of the world's energy requirements were generated. The efficient utilisation of this enormous quantity of fuel as a source of heat and power is of primary importance to the material well-being of mankind. The *per capita* rate of energy consumption in the U.S.A. is more than five times the world average (7,000 watts compared with 1,300 watts). In Great Britain, owing to increased efficiency in utilisation, at least four times as much useful energy is derived from a ton of coal as compared with two generations ago ; but there is still room for much improvement.

The rate of heat release which can be obtained from a particular fuel depends upon (a) factors inherent in the fuel itself, and (b) furnace and combustion chamber design. The word *coal* covers a multiplicity of highly complex carbonaceous substances possessing a wide range of properties : its more efficient utilization demands a fuller and wider appreciation of the effect of these properties and wider appreciation of the effect of these properties on the rate of heat release in particular circumstances.

Professor Riley discussed some of the difficulties in the way of a more rational utilisation of coal resources. If it were necessary to burn coal in a perfect world, each type of coal would be used only in the furnace or combustion chamber best fitted and adjusted for its particular combustible properties and to give the rate of heat release required. Unfortunately this is not possible owing to the uncontrollable variations which arise in both the mining and distribution of coal. The preparation of coal, can, however do something to smooth out such variations. For example, ash content can be reduced by cleaning, excessive swelling properties can be reduced by pre-oxidation, the nature and proportion of volatile matter can be modified by low or high temperature carbonisation, and it is possible that the evolution of volatile matter during combustion could be modified by chemical means. If complete gasification could be carried out at coalfields, high calorific gas could be piped to cities and factories with great savings in transport costs and labour and reduction in pollution of the air. Whatever method is adopted, it will be essential that pre-treatment be assessed on a strictly thermal or thermodynamic basis according to the use to which the coal is to to be put.

The Efficient Use of Fuel

By reference to two examples, from the experience of the Fuel Research Station, Dr. A. C. Monkhouse illustrated ways in which consumption of fuel could be made more efficient. In the first example he described how 40 power stations were visited and samples taken of deposits in their boilers. By relating the analysis of the physical and chemical properties of the deposits to the type of coal consumed and the combustion system in operation, it was possible to ascertain which types of coal were likely to cause least deposit and thus to increase the efficiency of each type of boiler and reduce the time it was out of action for cleaning. In the second example, he referred to the fact that smoke is due to incomplete combustion of coal and that the conditions in which smoke is reduced to a minimum are especially difficult to secure when boilers are fired by hand. During the war it was necessary to reduce the smoke from handfired boilers of ships in convoy and a smoke eliminator was devised which not only had the desired effect of reducing smoke, but also reduced the consumption of coal. The device has been used with savings of up to 10 per cent. on handfired Lancashire boilers.

Economy in Domestic Heating Systems

Mr. A. T. Pickles described experimental work by the Building Research Station on the effect on fuel consumption achieved by thermal insulation. Development of insulation has so far taken place mainly on the basis of laboratory tests but large scale experiments now being carried out at the Building Research Station on complete houses. The technique of large scale physical measurements is not new, but was greatly developed during the war, when, for instance, the magnetic fields of all ships were measured for degaussing. At the Building Research Station the temperatures maintained in a group of experimental houses, with families living in them, are being measured by remote recording instruments at a central station, with the object of determining the relation between the fuel usage and the thermal conditions obtained. By carrying out a heat balance, it will be possible to measure the efficiency of the heating appliance, and the effect of the thermal insulation.

Coal Economy in Domestic Heating

Professor J. D. Bernal said that the domestic fire belonged to an age of abundant coal, cheap labour and carelessness about

social amenities. More coal per household was used in Great Britain than in any country in Eastern Europe or America with harsher climates, and that without keeping ourselves as warm.

A 10 per cent. economy in domestic heating in itself would provide enough for the winter fuel stocks so urgently needed. The difficulty is to convert domestic heating to more effective use in a short time without undue capital expenditure and within the limits of national capacity. It should be possible, however, to see how much can be done with the minimum material supplies. In the first place, new construction should be such as not to perpetuate old wastes. Research is at present going on at the Ministry of Works to see how the new devices developed at the Fuel Research Station can be incorporated in dwellings designed to make the best use of the heat provided and to minimise heat losses. The experimental houses scheme of the D.S.I.R. and Ministry of Works should enable this to be done with the minimum of interference in traditional British domestic habits. For larger buildings and more dense urban development, use should be made of district heating and of heat pumps which may reduce the ultimate fuel consumption by as much as 50 per cent.

Large economies can only take place by modifying existing equipment, and research is badly needed into methods of increasing the efficiency of ordinary domestic fires and into providing cheap means of increasing the insulation of houses.

According to figures supplied by the Building Research Station the distribution of heat losses from a typical pre-war small house is roughly, in percentages, external walls 28, windows 12, ceilings and roof 15, ground floor 9·5, external doors 1·5, ventilation 30, hotwater run to drain 4. Much could and should be done by insulating the various points of heat loss, but by far the easiest way to reduce loss of heat would be to adjust ventilation which accounts for 30 per cent. of total loss.

Unfortunately, there is no scientific measure of how much ventilation is required for health, but it is fairly certain that in England, at least, far more air is used than is needed, out of a mistaken belief that it keeps down infectious fevers. If more attention were paid to removing smells (such as those due to cooking) by local ventilation, this figure of 30 per cent. could probably be reduced by at least two-thirds.

If the best methods were used both in getting greater value from our fuel and better effective insulation it might be possible to reduce coal consumption by about 30 per cent. and maintain the same domestic warmth.

Domestic Fuel Economy from the Electrical Aspect

Miss M. V. Griffiths described some of the many aspects of fuel economy in which the electrical industry is interested. The Electrical Research Association has carried out full-scale tests into the effects on the rapid warming of rooms by wall linings heated by electric hot wire radiators. It was found that metallised wallpapers with reflectivities greater than 0·6, were as effective as good insulating wall boards, in reducing the warming-up time; comfort being reached in 20 minutes instead of 1 hour without wall treatment.

Other sources of heat loss are due to inadequate insulation of hot water storage tanks, ' vagabond ' circulation of hot water in badly designed pipework and turbulent mixing of incoming high speed cold water with hot storage water in cylinders and tanks. Means have been found for reducing these losses to negligible quantities.

A solid concrete floor heated by buried electric cables forms a ' thermal store ' which can be used to tide over the peak periods. A typical floor will maintain a room at 55°F. for an expenditure of 4 watts per square foot and provide sufficient heat to maintain the temperature above 50°F. for 5 hours after switching off.

The heat pump as a method of heating is attractive to the electrical industry. The Research Association is using an experimental pump to carry out research into suitable sources of low grade heat and into the factors affecting the efficiency and control of the pump.

Developments in the Technology of Coal Carbonisation and Gas Distribution

In a paper which he was unable to deliver, Professor D. M. Newitt referred to the need for a substitution of the wasteful combustion of coal by more refined methods based upon electricity and gas. Major changes would make heavy demands upon the electricity and gas undertakings and upon appliance makers. The question arises whether the gas and electricity undertakings could accept the additional load and give the services required at an economic price. In the case of gas, coal is carbonised to give two secondary fuels, coke and gas, in a thermal ratio of approximately 2 : 1. Both can be stored in bulk, the storage capacity for gas, in any one undertaking, being usually sufficient to meet only its daily or, at most, its weekly peak load. For dealing with a rapidly expanding demand, efficient processes for the complete gasification of coal, the production of gas of a much higher calorific value than coal gas, and the storage in liquid form of the higher

calorific value gas might be required. New developments in the technology of coal carbonisation suggest that these requirements could be met.

The Reduction of Energy Requirements for Steelmaking

Mr. M. W. Thring described recent work on fuel economy in the steel industry. The fuel requirements of the industry are the product of the steel tonnage and fuel per ton of steel. The improvement of the latter figure has been going on slowly but steadily ever since steelmaking assumed its modern form around 1860. Nearly every stage from ore to finished steel product requires fuel, the detailed figures being of great interest, the later stages of manufacture of some finer forms of steel taking more fuel per ton than the actual steelmaking. Three methods of obtaining further improvement in these figures are being studied by the industry and its Research Association: (1) fuller use of instrumentation; (2) improvement of design of plant by study of fundamental laws; (3) development of radically new processes.

A recent full scale research on the Siemens open hearth furnace showed that full use of existing instruments offered the possibility of reducing the time of a single cast by 10 to 20 per cent., with a corresponding reduction of fuel, and that more exact control of the combustion conditions could reduce the fuel even more. Three methods of studying the fundamental laws governing the blast furnace open hearth furnace, soaking pits, reheating furnaces, etc., are being used, namely, laboratory experiments on a single chemical reaction, gas flow situation or heat transfer arrangement, model tests, and statistical experiments based on R. A. Fisher's work on the actual plant. Radically new steelmaking processes which are being investigated include the manufacture of high quality Bessemer steel by oxygen blowing, the execution of refining reactions in the ladle at comparatively low temperatures, and the use of quite new types of open hearth furnace such as one with one-way firing and the all basic furnace. The possibility can be envisaged of a quantum jump in the industry comparable to that in the period between 1850 and 1870 when the Bessemer and open hearth processes and the high-blast pre-heat for blast furnaces were introduced.

CULTURAL CHANGE

REPORT OF A COLLOQUIUM

Edited by Professor Daryll Forde (President of Section H, 1947)

As part of the programme of Section H (Anthropology) at the Dundee Meeting of the British Association in 1947, it was decided to invite a number of papers from social anthropologists dealing with different aspects of culture change among non-European peoples whose ways of life are being profoundly modified by the impact of Western industrial civilisation. It was possible in this way to bring together an exposition and illustration of an important trend in studies in social anthropology which has been developing considerably both before and since the war.

Extended summaries of the four papers, presented at this session of the Section's meetings on September 1, are printed below. Dr. Richards' paper sets out the historical background, practical inducements and theoretical considerations relevant to advances in this field, and Dr. Mair illustrates by an analysis of changes in African land tenure the way in which fundamental generalisations are being reached through comparative studies. Dr. Little and Professor C. von Fürer-Haimendorf illustrate the nature and complexity of the factors involved in cultural change as revealed in studies of West African and Indian peoples among whom they have worked.

Culture Change and the Development of Anthropological Theory

By Dr. A. I. Richards

Most students of human society, whatever their avowed objective, do, in fact, spend much of their time investigating processes of culture change. A people's culture is, by definition, their traditional heritage, but nevertheless their organised activities, their beliefs, their social structure and their artefacts are constantly subject to change. A culture reacts to a physical environment, to contacts with other cultures, and to the working of its own institutions which may be designed expressly to produce or facilitate change. To treat culture as a static phenomenon is a mere heuristic device.

Social scientists, however, differ in their

interests and methods. The archæologist, the historian, or the sociologist who wishes to trace the evolution of social forms, may select long periods of time in which to study the sequence of events and, as a result, may be able to frame general laws as to the nature of social change. The economist concentrates on variations in one special sphere of human activities. The anthropologist is reputedly concerned with static societies, small isolated communities in which change takes place so slowly that it is almost invisible and for which there are no written records of the past. Yet, paradoxically enough, the very nature of his material has led him to formulate a number of hypotheses as to culture change which could not easily have been made by any other type of social scientist, and which may prove to be amongst his most important contributions to our knowledge of social laws.

Anthropologists first began to interest themselves in culture change as the result of the methods they were forced to evolve for the reconstruction of the history of peoples for which no written or other records exist. But, as a by-product of this historical work, came a series of generalisations as to the processes of the 'diffusion' of traits from one culture to another. Graebner, Wissler, Dixon, Kroeber and others were in fact attempting to frame laws of culture contact, as was Rivers when he tried to classify different types of contact situations and the changes likely to be produced by the contact of superior and inferior peoples, or between groups of greater or less size. A large part of the anthropological teaching given in Universities twenty-five years ago was devoted to this type of study of culture change.

A new series of generalisations as to culture contact resulted from a shift in the theoretical interests of anthropologists during the twenties. More detailed field-studies and deeper sociological analysis made the older type of diffusion work seem artificial and mechanical. Malinowski began to publish the results of an intensive study of one particular community. He urged anthropologists to investigate primitive tribes as units actually functioning under present-day conditions and not as reflections of their own past history. Such an approach naturally focussed attention on the observation of changes going on in individual cultures whether through contact with other people or through other forces. Malinowski himself worked in a part of Melanesia in which society was, relatively speaking, stable, but a number of his pupils did their field-work in African communities which were being subjected to particularly powerful European influences. It was inevitable that they should turn their attention to the study of such changes and to describe the disruptive effects of western administration and industrialisation on African political, economic and family life. The practical importance of such investigations became apparent to the administrator in colonial areas and increased the demand for such work.[1]

Malinoswki's main theoretical contribution was a functional analysis of culture into a series of interrelated aspects, and this scheme he later adapted to form the basis of a more dynamic type of study of culture contact by which it would be possible to trace the series of related changes which would follow the introduction into a primitive society of, for instance, a new political organisation, a new creed, or a new cash crop. He pointed out that anthropologists working in situations of rapid change could not afford to limit themselves to the study of the native community only. The behaviour of the white administrator or missionary were as much a part of the 'total contact situation' as the native himself. Gluckman used the same concept in an analysis of a modern social situation in Zululand, and Kuper has described the whole of the social structure of the Swazi and their system of rank as part of the whole white-black structure of Swaziland and the Union of South Africa.[2]

Anthropologists began to adopt new techniques suited to the investigation of changing communities. They tried in the first instance to contrast conditions before and after European contact, or to search as Dr. Mair has described it, for 'a zero point' from which to reckon such changes. They illustrated changing social forms by selecting sample communities which had been more or less in contact with white civilisation. They began to use statistical methods to estimate the variations in behaviour of groups and individuals which are bound to be characteristic of a change situation. They collected village, family and individual case-histories, and made comparisons of the behaviour of different generations.[3]

Anthropologists have been accused of neglecting their scientific work for the sake of doing studies of practical importance to

[1] During the thirties the International African Institute sent nine of its fellows to different parts of Africa expressly to study the effects of European contact on different African societies, e.g. the Mende, Nupe, Tallensi, Kavirondo, Nyankole, Lovedu, Ngoni, Swazi, Nyakusa. The Universities of South Africa made special studies of changing conditions in African tribal reserves and towns.

[2] Malinowski, *Dynamics of Culture Change*, 1946; Gluckman, 'Analysis of a Social Situation in Zululand,' *African Studies*, vol. 14, 1940; Kuper, *An African Aristocracy*, 1947.

[3] Cf. *Methods of study of culture contact*, International African Institute, 1938.

the administrator, such as land-tenure, or urban surveys, but it is a mistake to put 'scientific' and 'practical' work in opposition, as is sometimes done. The application of anthropological knowledge follows the detailed scientific investigation; it does not precede it or do away with it. Moreover, it is as possible to write a scientific article on the position of the urban African as it is to write an unscientific one on totemism among the Australian aboriginees. A number of generalisations as to the processes which result from contact between European and primitive civilisations have been made as well as practical recommendations. Firth suggested, on the basis of Maori material, that there was a rhythm in the acceptance of the new culture, first an eager reception of European goods and ideas, then a rejection with a corresponding idealisation of the past. Chinnery and others have described the appearance of religious cults and revivalist movements as a reaction to the superior culture,[1] Schapera suggests that where Christianity comes in contact with primitive religious and magic systems the religious elements such as ancestor worship go, while the magic remains. The Wilsons have devoted a book to the enunciation of general laws as to the changes produced by contact between small and large-scale societies.[2]

American anthropologists have protested on the other hand that their English colleagues are pre-occupied with culture contact in a very narrow sense; that is to say the reaction between European, and mainly between British, and primitive peoples. Herskovits and Redfield and others have differentiated between the process of 'acculturation' that takes place between two peoples long in contact with each other, and 'culture contact' as used to describe the first stages of such a process. Redfield has studied Mexican communities, where Spanish, Indian and American cultures exist side by side, and Herskovits the mixed cultures of Haiti and Trinidad. Evans-Pritchard has advocated similar widening of the field by the inclusion of Mohammedan-pagan contacts in Africa. Firth has recently argued that the changes produced in primitive society by western industrialisation can be parallelled in Malaya, China, India and other regions where there are peasant societies not usually regarded as primitive.[3] He suggests in fact that anthropologists should concern themselves with primitive and peasant peoples all over the world and that they should abandon the term 'culture contact' for the wider concept of 'culture change.'

The new situation is one that needs some examination. Some anthropologists claim to study all peoples and not only those that are reckoned as 'primitive'; all realise that there are now very few peoples left who are quite out of touch with our own industrial civilisation. The anthropologist will increasingly need the help of social scientists accustomed to working in modern communities if he is to complete his picture of a total contact situation. He is already using many of their statistical and other techniques. Has the anthropologist then no further contribution to make to the study of culture change? Having thrown up a number of subjects for investigation must he now retire from the field and declare that the situation is too complex for him to handle with his own tools?

I believe that, on the contrary, the anthropologist's contribution to the study of social change is likely to be greater rather than less during the next decade. The intensive analysis of particular small scale cultures gives us the habit of examining the total sequence of changes produced by the introduction for instance of a cash crop or a new form of education, and to examine them in every aspect of social life. This tradition and its accompanying techniques will still, I think, produce a number of hypotheses as to cultural process which no other type of material is likely to yield. Again, the variety of small cultures we have had to study has led us to do some, at any rate, of the pioneer work in the field of culture change, and it still gives us the widest range of contact situations on which to base general laws. In fact I think it likely that one of our most fruitful fields of work in the future will be the study of the differential reactions of primitive peoples to contact with the same agents of change, or to similar processes such as urbanisation. Benedict, Kardiner, Linton and others have tried to account for these differential reactions in terms of differing personality structures, but comparisons on the basis of structural variation and an examination of the basic institutions in each culture have not yet been systematically developed.

Anthropologists have also the tradition of direct observation of human behaviour in small groups—families, households or villages—and it is on such observations that finer generalisations as to individual reactions to change must be based, and the very important process of the education in new values observed. This is a type of data that

[1] Firth, *Primitive Economics of the New Zealand Maori*, 1929; Herskovits, *Acculturation*, 1938.

[2] G. and M. Wilson, *The Analysis of Social Change*, 1945.

[3] Cf. Redfield's use of the term 'folk communities' for such people.

the historian has rarely had available in discussing change. Small scale studies of the institutional background and formalised morals of a people should prove a basis for psychological investigations of the individual reactions, and often of the individual maladjustments which are a phenomenon of rapid social change.

Changes in African Land Tenure

By Dr. L. P. Mair

CUSTOMARY African land rights were appropriate to a subsistence economy in which land is the basis of existence and therefore cannot be profitably exchanged for any other commodity. With rare exceptions there was ample land available in circumstances where no one wished to cultivate crops other than food crops. Cultivation was shifting ; where whole villages were periodically moved, permanent rights could not be established. Otherwise permanent rights of occupation existed over areas large enough to include both cultivated and fallow.

Everyone had a claim for land to cultivate in virtue of his membership of some community. Either he obtained an allocation from the territory of his lineage or it was allotted to him by a chief in return for political allegiance. His rights usually passed to his heirs. Land surplus to the needs of the group could be granted to an outsider, subject to the prior claim in case of need of a member of the group ; but this was never a commercial transaction. The principles characteristic of most systems were that every cultivator had recognised rights over a given area of land, which passed to his heirs, but the community, through its representatives, had the right to be consulted if rights were to be created in favour of non-members.

Early European observers thought there could be no security of tenure without full ownership. It is true that there might be political insecurity due to the arbitrary action of chiefs, but there was no economic insecurity in the absence of economic competition. Occasionally the assertion of customary rights has been an obstacle to the planting of permanent crops, but more often custom has adapted itself.

In modern conditions land has acquired an economic value as a scarce commodity. It has also become negotiable for cash. The development of a commercial attitude to land has been stimulated by the general tendency to substitute cash payments for gifts in kind in any situation where custom demands that a gift be made. Such gifts come to be regarded as payment ; the harvest gift of the tenant comes to be assimilated to a rent payment.

A comment which might be made on the process of culture change in general is that the conservative force of tradition is not proof against the attraction of economic advantage, if that advantage is sufficient and is clearly recognised. Of course it does not follow that the resultant changes are necessarily to the general benefit.

Nowadays individuals are prepared to offer money for the exercise of rights in land because they hope to turn those rights to profit in terms of money. They may formally approach the heads of a land-holding group in the traditional manner, but it is recognised on both sides that the group is surrendering its rights. From this it is a short step to open sale.

Complementary to these individuals are those who need money and find in the surrender of land rights a way to meet the need. The method is usually to pledge their land, a transaction recognised by African custom in case of a debt incurred, for example, in order to pay a fine. To-day there are many more opportunities for getting into debt, and the debts incurred are heavier. Gold Coast cocoa farmers established in prosperous times a standard of living that in most years they cannot hope to maintain without borrowing. They do so by pledging their land for money loans at exorbitant interest. Though it is true that progressive farmers need credit, the amount that has been raised to improve the land must be a small proportion of total African indebtedness.

It is now profitable for an individual to cultivate a much larger area of land, and he can do so by ploughing or by employing labour. Those persons who have the authority to allot the land of the group can acquire rights of occupancy over large areas by encroaching on the reserve that should be maintained for future expansion. Another method is for an individual to redeem an area pledged by a group and assert sole rights over it.

Tenants are now really insecure, partly for economic reasons—a man is sometimes evicted just when he has planted up his land with a commercial crop—and partly through the assertion of prior claims by a member of the land-holding group. In the Kikuyu reserves a young man who has grown up in the settled area and decides not to become a labour tenant must return to the reserve and find a holding on the land of the group to which he is related. If a tenant who has succeeded his father and grandfather on his holding is evicted for this reason, he may well feel that he is the long-established occupier who is turned out for a stranger.

Every position of economic privilege is tending to become a private perquisite rather than a position of trust. Many privileges of African chiefs have been curtailed in order to prevent abuses of power. But the ultimate right over land still rests with them, and to remove that would be to remove one of the most important sources of their authority. Yet this right can become a means of abuse in modern conditions.

Changes in African land tenure have been in line with the general response to increased opportunities of economic gain, but those advantages are at first perceived only by the minority and the result is an inadequate adaptation to new conditions.

A Study of Modern Social Change in a West African Community

By Dr. K. L. Little

In the Sierra Leone Protectorate, as in other parts of West Africa, the prestige of the European and of European civilisation is very great. Its material aspects, in the shape of manufactured goods, housing, etc., offer powerful incentives of a social as well as economic kind to the native people. But there are few ways of satisfying such ambitions except in clerical or some other form of employment for which a European education is required. Farm-work provides a young man with little more than his keep, and even senior posts in the Native Administrations compare unfavourably with a job in Government service or with one of the mercantile firms. The urge towards literacy constitutes, therefore, a fundamental factor in the social changes described below.

In the process of acculturation, two additional sections of Sierra Leone society—the African Creole and the European—have also to be taken into account. The Creoles, who are descended from the original settlers of Freetown and the Colony, have always emulated western habits, and in the present situation they fulfil a special role as cultural media owing to the social distance which separates the ordinary European official from the African community. In the field of inter-personal relations, the Creole missionary, clerk, trader, and teacher supplies a code of etiquettes, and sets a standard of social attainment, which in spending power, educational accomplishments, and mannerisms is approximately intermediate to that of the Europeans and the native people of the Protectorate. It would appear that every native individual undergoes a certain amount of 'creolisation,' i.e. the process of taking on Creole customs, once he begins to disassociate himself from tribal life. The tendency shows itself in a variety of ways, including social selection and adoption of the Creole *patois*, and the general process takes place within a context of group consciousness and resistance from the parties concerned. There is a certain amount of antipathy between the Creoles as a group and natives of the Protectorate who are literate, and between literate and illiterate Protectorate people. Attitudes also vary reciprocally between the Europeans and the various sections of the African community.

Indeed, social differences between the groups concerned are sufficient for 'European,' 'Creole,' 'Literate Native,' and 'Illiterate Native' to be regarded as the labels of four fairly distinct classes. These are marked off from each other by various forms and degrees of social distance, the most obvious of which is the residential separation of the 'European' and the deference paid to it by the rest of society. Moreover, the fact that the classes in question are esteemed according to their possession of appropriate educational, occupational, and other traits means that they can be arranged in order of social precedence. For example, the 'European' class, by virtue of its political position and the prestige attached to European customs, is in hierarchical control of the system as a whole. Membership of the classes is to be adjudged on the basis of the individuals composing them, having similarity of occupation, wealth, and education, similar modes of life, a similar stock of ideas, feelings, attitudes, and a feeling of belonging to one group.

Thus, most members of the 'Creole' class have attended a secondary school. Occupationally, they are found in the higher grades of the Government clerical service, or are senior schoolmasters, factors for the European firms, or members of the clergy. Christianity is usually practised. On the whole, relatively few Protectorate-born persons fulfil these criteria. Class consciousness is felt mainly as appreciation of the superior standard of living which the individuals concerned enjoy over the rest of the African community, and in their greater knowledge of the 'correct' way to behave socially. The men wear European clothes on all occasions, and evening dress for dances. The women usually wear a head tie and print frock during the day time and on most week days. On Sundays, a silk dress with hat and stockings are worn; 'long' frocks are *de rigeur* for dances.

The 'Literate Native' class consists in the broadest sense of every other African who has been to school, or can speak English with reasonable proficiency. It is sociologically inclusive not only of the majority of educated Protectorate people, but also of the

lesser educated, less wealthy Creole. To a large extent, it is ' Protectorate conscious,' but literate Protectorate-born people and the Creole who moves with them meet, in some respects, on common ground in relation to the illiterate and tribal group. The upper stratum of this class includes junior clerks in Government service, members of the staff of the railway, artisans, motor drivers, and male and female nurses. It includes Moslems as well as Christians, and marriages are polygamic and monogamic. The lower stratum comprises individuals in clerical employment outside the Government, such as assistants to Syrian traders, and tailors, and the permanent but non-clerical staff of Government departments. General behaviour is much more on traditional lines.

Members of this class still retain a close connection with tribal affairs in some cases, and their help and advice are often sought.

Inclusion of the illiterate people as a class within the system is justified on the grounds that it is out of their ranks that the ' Literate Native ' class is recruited. In addition, they are clearly characterised as a social class by similarity in occupation, which is farming, in traditional and tribal custom, in a lower standard of living than the rest of society and, to some extent, in consciousness of themselves both as a cultural and social group.

The hierarchical system thus described indicates the dynamic factors at work in a situation which it is conventional to classify as acculturative, and it also exemplifies the main conditions which appear to accompany the process of social change itself. Briefly, these conditions may be summed up as follows :

(1) That an increasing number of individuals no longer acknowledge the tribal controls and other sanctions to which they were formerly subject ;

(2) that the older values and forms of prestige are being replaced by new ones ;

(3) that there is a growing tendency for an individual's status and role to be socially assessed with reference to society as a whole, rather than to the particular kindred or lineage to which he belongs ; and

(4) that the kind of relations which individuals whose living is gained by some European form of occupation have with each other is giving rise to a type of social structure which is based on social class rather than kin.

The Aboriginal Problem in Hyderabad State

By Professor C. von Fürer-Haimendorf

WHILE the problems of cultural change arising from the impact of western civilisation upon African societies are the subject of a considerable literature, there exist few accounts of the social and economic phenomena resulting from the contact between primitive and advanced communities in the sub-continent of India. Yet cultural change is a cardinal factor in the shaping of the future of twenty-three millions of Indian aboriginals who stand outside the orbit of Hindu and Muslim civilisation. There is, however, one fundamental difference between the problems of acculturation in India and in Africa. The recent changes in African culture patterns are largely caused by the influence of Europeans on the indigenous societies. In India, on the other hand, most aboriginal tribes have had little direct contact with the exponents of western civilisation and the transformation of their culture and mode of life is largely the result of contact with the more advanced Indian civilisations.

Hyderabad, the premier Indian state, with an aboriginal population of over 250,000, offers a wide range of examples illustrative of the diverse reactions of primitive communities to contacts—both voluntary and enforced—with Hindu and Muslim populations. Here the aboriginals inhabit mainly the hill-tracts and forest-areas situated on the borders of the State along the rivers Kistna and Godavari, regions which until recent years were remote from the centres of civilisation.

The Chenchus of the Amrabad hills on the border of Madras Presidency are a semi-nomadic people of food-gatherers and hunters. In groups of a few families they live in the deciduous forest and subsist on wild jungle produce, such as berries, roots and tubers, and a small amount of game. They dwell in bamboo huts and leaf-shelters, and often camp for weeks under overhanging rocks. For centuries they encountered no other outsiders than the pilgrims journeying to a Hindu temple above the Kistna gorge and the Telugu peasants of nearby plains villages, where they sometimes went to barter jungle produce for iron, salt and cloth. Such contacts were almost entirely voluntary and the Chenchus were free to accept or reject any element of the rustic Hindu civilisation of the plains.

A study of these ' Jungle ' Chenchus, who still persist in their old mode of life as food-gatherers, reveals that acculturation on a modest scale occurred without a basic readaptation of their economic system or

their social organisation. Iron tools, for instance, were introduced to improve established techniques but not to develop new economic activities. Thus digging sticks were furnished with iron spikes and arrows with crude iron heads, iron knives were employed in basket-making and iron axes in the construction of huts and shelters. The borrowed items were fitted into the traditional culture pattern of the Chenchus, but there was no attempt to adopt the plainsmen's method of food production or to imitate their style of housing. The Chenchus seemed content to acquire by barter such products of their neighbours as immediately rewarded existent drives, while through the social interaction involved in this barter they seem to have learnt Telugu, which has completely displaced the older tribal language.

A similar process occurred in the sphere of religion and social custom. Without abandoning essential traditional beliefs, the Chenchus took over certain caste rules such as the taboo on the eating of beef and the attitude towards 'untouchables,' and they adopted the use of cooked rice and turmeric for food offerings. The results of the Chenchus' selectivity in the fields of both economics and ritual were twofold; though using tools produced by more advanced populations they remained on the level of hunters and food-gatherers, but on the other hand, they rose to a fairly high rung in the caste system by conforming to some of the customs of caste Hindus.

Fundamentally different from the voluntary adoption of individual cultural elements in the course of casual trade contacts, was the enforced readaptation of Chenchu culture under the pressure of administrative action. The introduction of forest conservancy and the subsequent commercial exploitation of forests put an end to the Chenchus' freedom to roam the forests and barter their wild produce. In Madras Presidency Chenchus were forcibly concentrated in large settlements and provided with the means of cultivation. But the response was largely negative; very few Chenchus took to plough cultivation, and after nearly half a century of supervision the Chenchus in these settlements continue to depend on the labour and the provisions provided by the Forest Department.

In Hyderabad there was for long little deliberate interference with Chenchu economy. Yet, of themselves, some families began to embark on cattle breeding, keeping a few buffaloes for the sake of their milk and the exchange value of calves. Novel as this occupation was, it did not conflict with their seasonal migrations, and could be added to traditional habits. The scheme for the amelioration of the Chenchus' economic conditions recently introduced by the Hyderabad Government takes into account their unpreparedness for a radical economic readaptation; those still inhabiting the forest have been given a respite through the creation of a Chenchu Reserve, which secures them their hunting and collecting grounds; the collection and sale of forest produce has been organised on co-operative lines and Government has encouraged the breeding of cattle by the free distribution of buffaloes to every family.

Other aboriginal tribes of Hyderabad were faced by the same challenge of contact with advanced populations and have met this challenge in different ways. The Reddis, for instance, a tribe of shifting cultivators in the Eastern Ghats, south of the great Godavari gorge, found their hills surrounded by Telugu peasants almost identical in cultural make-up to the Chenchus' present neighbours. Yet the readjustments in their culture pattern followed a course very different from the acculturation process taking place among the Chenchus. In their old economy the Reddis, too, relied to a certain extent on the gathering of wild jungle produce. But long before they came in touch with Hindu peasants they had learnt to raise food by cultivating millet and pulses on clearings carved from the forest, and by breeding domesticated pigs. Their agricultural methods were primitive—axe, digging-stick, and sickle being their main implements—but the principle of plant raising was firmly established in their culture, and when they encountered the fully developed agricultural civilisation of the Telugu people they realised the advantages of plough and animal-traction and wherever the environment was favourable they effected the transition from shifting cultivation to a settled peasant economy within two or three generations. In this case the innovation of plough-cultivation was readily accepted, because it was aligned with the existent orientation of Reddi culture, and involved an enrichment and not a revolution of the traditional mode of life. Permanent cultivation led in turn to larger and more stable settlements, and these favoured sustained social interaction with neighbouring populations different from the casual trade-contacts of unsettled food-gatherers. But though the Reddis copied certain customs and were anxious to secure specialised goods used by their neighbours, they did not go so far as to learn new crafts or to embrace new occupations; they supplemented their own products by trade and hired specialists from neighbouring groups for activities connected with borrowed

rites and ceremonies. A breach in these mutually beneficial relations between the Reddis and the neighbouring peasantry occurred, however, when forest contractors began to employ Reddis as labourers and led them deliberately into economic dependence. This they achieved by fostering the growth of new wants which could be satisfied in no other way than by work for wages. A period of domination by outsiders followed upon the ' benign ethnic relations ' of earlier days, but the recent exclusion of forest contractors and the establishment of a co-operative society of aboriginal forest workers under Government control has initiated a new phase, the cultural effects of which are not yet apparent.

In the sphere of religion and ritual the selectivity of Reddi culture could operate without appreciable interference by outsiders with vested interests. The aspects of Hindu ritual adopted by the Reddis are different from those that found acceptance among the Chenchus. The Reddis, familiar with animal sacrifices in honour of the Earth Mother and various hill-deities, readily accepted the bloody sacrifices offered to the mother-goddesses of rustic Telugu civilisation, but the belief in the supreme and benevolent god Bhagavan which the Chenchus share with their Hindu neighbours has as yet found no place in Reddi thought.

Chenchus and Reddis are comparatively small communities which, though persisting until recently in a very primitive economy, succumbed to the linguistic pressure of neighbouring advanced populations and adopted Telugu, at first presumably only for purposes of trade, but ultimately as their only language to the exclusion of their original tribal tongues. The Gonds, on the other hand, who are a branch of the great Gond race and alone in Hyderabad number well over 150,000, have maintained their own language and with it a rich oral literature of myth and legend. Unlike Chenchus and Reddis they have been in touch with Hindu populations for several hundred years, but acculturation occurred only in specific spheres of life. Economically the Gonds have adapted themselves to the system of agriculture prevailing among the other peasant populations of the Deccan and it was only their system of land tenure which retained certain features out of tune with modern conditions. They learnt new skills, such as the blacksmith's art and carpentry, and imitated in style of dress and housing the agricultural castes among their Hindu neighbours. But the influence of Hinduism on religion and social customs remained on the surface. While both Chenchus and Reddis comply with the Hindu taboo on beef-eating, the Gonds sacrifice cows and freely eat beef. They have adopted a number of Hindu feasts, yet their myths refer to Shiva and Parvati in decidedly irreverent terms and in the performance of Hindu rites they show none of the seriousness and religious fervour which characterises the cult of their clan-gods. Social relations within the tribe are ruled by a complicated system of phratries, clans and sub-clans, and there is as yet no sign of Hindu ideas of ' caste ' disrupting the fundamental unity of the tribe.

A decline of tribal life set in, however, when outsiders of Hindu and Muslim stock penetrated into Gond country and took possession of part of the cultivable land. Skilfully exploiting the difference between the Gonds' traditional system of land-tenure and the land laws of the State, these settlers were able to oust entire communities from their ancestral lands, and a time of acute conflict between aboriginals and newcomers followed upon the period of peaceful acculturation. Administrative action on the part of H.E.H. the Nizam's Government has succeeded in limiting this conflict and in preventing any further alienation of Gond land. A Gond Education Scheme instituted in 1943, is based on traditional Gond culture and the use of Gondi as medium of instruction in all schools. With the subsequent emergence of Gondi as a written language, and the teaching of Urdu and Marathi in the Gond schools, a new phase in the cultural and social interaction between aboriginals and neighbouring populations has been inaugurated, but it is too early to discern the eventual result of this most recent of acculturation processes.

Cultural changes as observed among the Hyderabad aboriginals exhibit a selectivity of primitive peoples in their borrowing from advanced populations, which accounts for the difference in results when several tribes came in contact with the same dominant civilisation. This selectivity makes it extremely difficult to foretell the outcome of any culture contact and calls for the fullest historical study of individual cases of acculturation.

CONFERENCE OF DELEGATES OF CORRESPONDING SOCIETIES

DUNDEE, 1947

DURING the spring and summer of 1947 an attempt was made to renew contacts with the Societies in correspondence with the Association before the war. A circular letter was sent to 171 Societies intimating that, on the resumption of Annual Meetings of the Association, a Conference of Delegates of Corresponding Societies would be held at Dundee and inviting suggestions for topics of discussion. Replies were received from the Secretaries of seventy Societies. A digest of their comments was prepared for the President and was subsequently incorporated in his Address to the Conference. The Conference was held in two afternoon sessions on Thursday, August 28, and Monday, September 1, and was attended by delegates from thirty-seven Societies, of which a list is given at the end of this report.

AT the first session Dr. J. Ramsbottom read his Presidential Address on 'The Natural History Society' (which is printed below) and, at his request, it was followed by discussion. At the conclusion Professor Balfour-Browne gave notice of a motion he would bring forward at the second session, and the President and Secretary were also asked to draw up an agenda for that session, incorporating any additional matters that had been raised either in the Address or in the discussion.

At the second session the following propositions were discussed :

1. That the British Association be requested to renew the annual publication of the list of papers published during the year in the Journals of the affiliated societies.
2. That the more important contributions to the transactions of Corresponding Societies should be reprinted in an annual volume by the British Association (through a grant in aid from Government funds administered by the Royal Society).
3. That a central committee to co-ordinate the activities of the various Unions and County Associations be formed, and that the ways in which such a committee might be of service, should be discussed.
4. That the possibility of arranging regional panels of lecturers—their scope and financial implications, should be examined.
5. That the relation of local scientific societies to the British Association and the part they might play at a higher level in the Association's affairs, should be discussed.
6. That the production of large scale basic maps, as a means of classifying and correlating natural history records, should be undertaken by the British Association.

The first topic was proposed as a motion by Professor F. Balfour-Browne (representing the Dumfries and Galloway Natural History and Antiquarian Society) and seconded by Professor G. D. Hale Carpenter (representing the South-Eastern Union of Scientific Societies, the Ashmolean Natural History Society of Oxford and the Royal Entomological Society). After discussion, wholly favourable to the scheme, the motion was passed unanimously for recommendation to the Council of the Association.[1]

The second and third topics were discussed in conjunction. There was a difference of opinion as to the advisability of proceeding with either scheme because they might lead to unnecessary duplication of publication, and this was undesirable at the present juncture.

Moreover, if the Council adopted the motion already passed, the published list would go far towards drawing attention to the work of the several Corresponding Societies.

No vote was taken on these items of the agenda, but there was an understanding that they would be kept in mind for a future occasion.

On the question of arranging regional panels of lecturers who would be prepared to visit Corresponding Societies, no conclusion was reached. Several delegates welcomed the idea but stressed the financial difficulties of their societies. Others considered that their societies should be encouraged to rely upon their own members for their programmes of meetings though occasional visits from others would be welcome.

[1] On receiving this resolution the Council decided to refer it for consideration by a Committee previously appointed to draft a scheme for a British Association Year Book of Science.

That local scientific societies might take part, at a higher level, in the affairs of the Association was not considered feasible. Their delegates to the Conference had the same opportunities, in this regard, as any other member of the Association, and the resolutions forwarded from the Conference were always matters of extreme interest to the Council.

Lastly, the question of basic maps for the plotting, classification and correlation of natural history records was opened by Dr. Alice Garnett (representing the Geographical Association). In the discussion it was pointed out that maps of this type were being constructed for certain areas by the Council for the Promotion of Field Studies, and it was thought that the time was hardly appropriate for the Conference to take action until more evidence of the kind of map required was available.

The Conference was attended by representatives of the following societies :

Ashmolean Natural History Society of Oxford.
Associated Learned Societies of Liverpool.
Association of Applied Biologists.
Association of Women Science Teachers.
Blackburn Philosophical and Scientific Society.
Botanical Society and Exchange Club of the British Isles.
British Mycological Society.
British Optical Association.
British Social Hygiene Council.
Caradoc and Seven Valley Field Club.
Cardiff Naturalists Society.
Croydon Natural History Society.
Darlington and Teesdale Naturalists Field Club.
Devon and Cornwall Natural History Society.
Devonshire Association.
Dumfries and Galloway Natural History and Antiquarian Society.
Dundee Naturalists Society.
Edinburgh Geological Society.
Engineers Study Group on Economics.
Geographical Association.
Glasgow and Andersonian Natural History and Microscopical Society.
Hampstead Scientific Society.
Hastings Natural History Society.
Hertfordshire Natural History Society.
Liverpool Botanical Society.
Liverpool Geographical Society.
Northern Naturalists Union.
Plymouth Institution.
Royal Entomological Society.
School Nature Study Union.
Society for the Preservation of Nature Reserves.
South-Eastern Union of Natural History Societies.
Teign Naturalists Field Club.
University of Durham Philosophical Society.
Universities Federation for Animal Welfare.
Warrington Literary and Philosophical Society.
Yorkshire Geological Society.

THE NATURAL HISTORY SOCIETY

ADDRESS BY

DR. J. RAMSBOTTOM

PRESIDENT OF THE CONFERENCE OF DELEGATES

IT is customary for a President to express his appreciation of the honour done him in the election to such high office, be it for a shorter or longer period. In following this time-honoured custom I may remark that I am particularly conscious of the trust which the Council of the British Association have placed in me in selecting me to preside over the present deliberations of this section, for I know with what interest it views the future development of local scientific societies and the part they may play in the affairs of the nation.

After a period of what might almost be regarded as cosmic upheaval, it behoves us to take stock of our former methods and customs and consider what should be, and could be, profitably developed—what amongst the flotsam and jetsam of our national and civic life can be and is worth retrieving and what is irretrievably lost.

What is the position of the local scientific society? There is a widespread view that this has had its day, that it is a relic of Victorianism with modes and fashions outdated, and that it has no prospects other than a gradual peaceful passing. This is an extreme view and there are various modifications of it which all here must have heard. At the other end of the scale is the belief that

as local societies have in the past played an important part both in science and in education, so in the future they will provide means of accomplishing much in these which otherwise would be wanting, not forgetting that companionship in the contemplation of nature which makes all men brothers.

It is because I hold this last view fervidly that I am addressing you to-day, and as most of you are present because of that same belief the necessity for stating a case does not arise—non-attendance at church is hardly an appropriate subject for a sermon. Better that we should consider and discuss how best we can arrange our affairs so that the greatest benefit shall result from our efforts. We must not be satisfied with a passive belief, we must not be satisfied with the past records of our individual societies and the fathers who begat them, but must decide the legitimate scope of our province and co-ordinate our efforts to develop it.

Local societies had their origin for the same purposes as the so-called learned societies and even as the old universities—the dissemination or communication of knowledge and the furthering of research. Both *universitas* and *collegium* had originally the meaning association or community: as Rashdall relates, the Pisan captives at Genoa formed themselves into *Universitas carceratorum*, and to come nearer home, the Senators of the College of Justice are the judges in the Supreme Court in Scotland. The founding of Institutions for the pursuit of learning with their privileges and endowments, which marked the fourteenth and fifteenth centuries, led eventually to our modern universities. The bequest by Sir Thomas Gresham of his house in Bishopsgate Street to become Gresham College (on the death of his wife, which happened in 1596) where free lectures were to be provided for all who cared to attend, shows an attempt at the wider dissemination of knowledge. The salaries of the Professors were derived from the rents of the shops in the Royal Exchange, and one of the seven subjects—Divinity, Astronomy, Music, Geometry, Law, Medicine and Rhetoric—was dealt with each day.

It was at Gresham College that the Royal Society first met. As John Evelyn writes on December 9, 1660, 'I was now chosen (and nominated by his Majestie for one of the Council) by suffrage of the rest of the Members, a Fellow of the Philosophic Society now meeting at Gresham College, where was an assembly of divers learned gentlemen. This being the first meeting since the King's return; but it had been begun some yeares before at Oxford, and was continued with interruption here in London during the Rebellion.' The continuation 'There was another rising of the Phanatics, in which some were slaine' apparently refers to something else, but on August 13, 1662, we have 'Our charter being now passed under the broad seale, constituting us a Corporation under the name of the Royal Society for the improvement of natural knowledge by experiment, was this day read.' We need not consider further the charter or the history of the Royal Society. What we have in essence is the meeting of men interested in the furtherance of natural philosophy, and we may note that it provided considerable amusement to many who were not.

In the eighteenth century literary and social clubs abounded, meeting in well-known coffee-houses and taverns; many of these circles have their place in the history of the times, but are merely mentioned as indicating how the spread in learning led to associations of those with special interests.

But though London was the centre, all learned people were not segregated there and travel was difficult. 'Literary and Philosophical Societies' began to be formed elsewhere: Edinburgh 1739, Manchester 1781, Newcastle 1792, and so on. Some of these embraced all knowledge, others tended to lay more stress on natural philosophy. The Lunar Society ('Lunatics') founded by Erasmus Darwin, so-called because the meetings were arranged near the time of full moon for convenience in returning home from the houses of its members where they were held, was famous in its day, for it included James Watt, Joseph Priestley, Josiah Wedgwood, Samuel Galton, Matthew Bolton, and William Withering. Perhaps if it had not been so wide in its interests, and had left aside the implications of the French Revolution, it might have continued, like so many, till to-day.

During this period specialized societies began to make their appearance. The Botanical Society was formed in 1721 but lasted only until 1726. Similarly short lived were the entomological societies—the Aurelian Society (1745-48), a second Aurelian Society (1762-1766), and the Society of Entomologists of London (1780-82). The Society for Promoting Natural History, founded in 1782 (-1822) may be regarded as the forerunner of the Linnean Society of London, 1788, which was in some ways the begetter of the Zoological Society, 1825. The Geological Society was founded in 1807, and the Entomological Society, after several attempts, in 1833.

The Natural History Society may be considered a product of the Victorian era. It was essentially an association of people interested in nature study at a period when systematic botany and zoology were generally

regarded as the main part of these subjects. One of their chief objects has always been the making of botanical, geological and zoological records, and many of our local Floras and Faunas were due to their activities. When systematic botany fell into the doldrums at the English Universities, the Natural History Society proved valuable as a centre of learning : I suspect that much the same can be said about systematic zoology. Taxonomy has recently had a good deal of lip service paid to it in various quarters, but I feel that more real service has been done throughout the years by those amateurs who have been the mainstay of the local societies. Some attained a world-wide reputation in their subject though few in recent years received any so-called 'recognition.' It would be a tragedy to science if amateurs of this type were to die out, but I am convinced that, despite lack of encouragement, the intrinsic interest in classification will survive. The natural history society, which is their habitat, even if not always their breeding ground, should be stimulated to further effort.

At the present time most local societies carry on much in the way which was so profitable fifty years ago. Since then there has been a crop of societies and clubs dealing with special branches of biology : but the natural history societies continue, though many cannot be said to flourish. Some, under the stimulus of one or more members have tended to specialize, but undue specialization defeats its own ends ; sections acting as local branches of the larger societies dealing with these subjects would be more profitable. Those societies which include literary as well as scientific subjects certainly benefit by having some at least of their meetings entirely devoted to the several sciences.

The federation of local societies into regional unions, beginning with the Yorkshire Naturalists' Union in 1877, has proved profitable and stimulating. Dr. F. Buchanan White in an inaugural address to the East of Scotland Union of Naturalists' Societies at a meeting in Dundee in 1884, clearly stated the advantages of such a Union—he stressed that the chief object was to carry on more effectually and more thoroughly the promotion of the study of natural science. An isolated society tends to subside into a less healthy condition than one which is stirred by a spirit of healthy emulation. Contact of members of different societies prevents them from getting into a groove. There is also the possibility of a Union undertaking some composite study of the natural history of the area covered by its component societies and co-ordinating and perfecting their studies of the different groups. Unfortunately the East of Scotland Union ended at Buchanan White's death in 1895.

All Corresponding Societies affiliated to the British Association have received a series of questions dealing with both general and particular problems of interest to local societies, and have been invited to send answers, comments and suggestions. The remainder of my remarks are based on them.

One proposal that has been made is that there should be some form of collaboration between the different Unions. This would seem to offer many of the advantages which the Unions themselves bestow. In my opinion the several Unions should remain distinct, but there should be a co-ordinating committee dealing with common interests and the exchange of information and ideas. Healthy and friendly competition would result.

Most natural history societies lament their small membership, particularly the lack of young recruits.

Some societies have special fees for young people, some have special lectures or courses : many schools have natural history societies, and boy scouts and girl guides have their badges for proficiency in nature craft : the wireless often broadcasts nature talks and the cinemas show an increasing number of good nature films : there are also the local Museums with often excellent exhibits of plants, fossils, birds and their eggs, butterflies and other insects, and similar instructive series, sometimes arranged in attractive habitat groups. This seems enough in all conscience, but somehow there appears to be a lack of drive. I am convinced from what I have seen at the Haslemere Educational Museum and in some school natural history classes, and from my own experience, that the only way to get satisfactory results is to have organized excursions under expert guidance, so that there is the thrill and sport of collecting specimens and the satisfaction of having them named correctly. There should also be some place where specimens obtained by young enthusiasts can be identified, and, if of interest from any point of view, exhibited with the name of the finder. A specimen so exhibited in a local museum or recorded in a society's proceedings, will act as a stimulus to many. Competitions arranged for young members of a society also adds zest to their studies. It may be considered that this is cheapening the study of nature—but we are competing for something of value against much that is shoddy, as well as for the glittering prizes. The enrolment of younger people is a task of national importance, for the country will need an increasing number of trained biologists, and it is beyond

question that field work is the most profitable method of approaching many fundamental problems as well as of inspiring a true interest in biology. Many eminent biologists had their blooding in their local society and some do not fail to renew their acquaintance by giving occasional lectures.

Though the educational side of the matter is stressed here, care should be taken not to suggest compulsion. The local education authority might finance transport, but the place of the science teacher in any scheme has to be considered very carefully. Science teachers are often most valuable members, for if they take up field work they can use their training to advantage—training which unfortunately otherwise is useless without the impedimenta of the university laboratory. But they should be members and not be in charge of any of their pupils, for otherwise field study tends to be 'another subject' rather than a *joie de vivre*.

Many local societies take the educational side of their activities most seriously. Others, however, fail, I think, in being too 'respectable.' Conditions of life have changed greatly since 1914, and more particularly since 1939. One of the problems we have to face is how these changed conditions affect local scientific societies. One obvious change is the incidence of comparative wealth and leisure. The artisan class with its five-day week and money sufficient to run a car, is in a totally different position from what it was in my younger days, but it was then that some of the so-called working men naturalists were content to tramp thirty miles or so over the moors on Sundays in search of a rarity. If scientific discovery is to have its proper outlet in industry and not to be merely devoted to speeding up, it is likely that what seems to be excess mollycoddling in times of national crises, will come to be regarded as the proper dues of scientific organization, the benefit of man's thought on man's labours. Whatever the distant future may hold, however, we have at present a large proportion of the people better educated on the average than formerly, with ample leisure time. Football, cricket, racing, swimming, boxing, and suchlike, provide exercise for the few, and outdoor excitements for the many. Cinemas, wireless, betting, football pools, darts, newspapers, and the social life of the local pub, provide the indoor recreations for most. After a day's manual labour or clerical work, many are doubtless satisfied with such methods of spending their leisure. It is certain, however, that some get interested in a special study stimulated thereto by a note in a newspaper or magazine, a wireless talk or perhaps some chance remark of a work-mate. Having indulged in almost all these pastimes I should be the last to decry them, but they seem in total an unsatisfactory way of passing all one's free time. It has been well said that the true aim of education should be to teach a man how to spend his leisure. The interest which so many additional people took in gardening as a result of the 'dig for victory' movement, underlines the point that I am trying to make, which is that with proper stimulus and direction there would be found a reservoir of natural historians. I do not for one moment suggest that everyone would be interested other than very superficially, even if that. Even with what is regarded as a true education there would be preferences: even in the British Association we specialize, following our choice for one or other good reasons, and are gradually expending the alphabet in our sub-divisions.

One activity which local societies could accentuate is that of carrying the practical knowledge of natural history to their fellow townsmen. There are difficulties, some of class, some of history or tradition. One simple point. How many societies with mid-week excursions concern themselves about early closing day? How many associate in any way with the British Legion or working men's clubs? It may be pointed out that the new Education Act places on the local Education Authorities the responsibility of encouraging the further education of adults. It is therefore most important here as with scholars that local scientific societies should have as close a liaison as possible with Education Authorities.

Some of the points raised in the letter which was circulated to Corresponding Societies have been already mentioned—and are open to discussion.

Most societies recognize that the work most appropriate for them is the making of local records. There are often serious gaps in less popular or more difficult groups, but this should be a challenge and not a subject for despair. Records should be made of changes in plant and animal populations which are constantly taking place, and an effort should be made to relate these to the factors bringing them about. This implies ecological and biological studies. Sites of archaeological, antiquarian or geological interest should be investigated, and phenological observations are welcomed by the Royal Meteorological Society. It needs no stressing that the essence of a record of any kind is its exactness, and a wrong identification is, at best, useless: put bluntly it is a lie. As a final resort there is usually some expert willing to give an opinion.

With the possibility of an increase in

number of nature reserves there is additional opportunity for detailed studies on a broad ecological or biological basis. Indeed, the local natural history societies might play a large part in protecting these areas and in noting others that are worthy of local or national preservation, a point which has been stressed in the recent Report of the Wild Life Conservation Committee. I should like to pay a tribute to the work already done in this way by the County Committees who provided material for the conclusions drawn by the Nature Reserves Investigation Committee, with Dr. G. F. Herbert Smith as secretary—conclusions and suggestions adopted almost in their entirety by the national sub-committee as they acknowledge. Note should also be taken of the work of the Norfolk Naturalists' Trust in preserving local nature treasures and the good start made by the recently constituted Yorkshire Naturalists' Trust in acquiring Askham Bog.

Co-ordinated mass observations on a national scale require special instructions if they are to be carried out by members of local societies. There is not the available experience and training for tackling some of the problems that would prove amenable to such methods. The successful campaign against the Musk Rat, and that which is being waged against the Colorado Beetle, however, show that even the untrained observer has his uses. The majority of replies to the query about mass observations on social and economic problems, suggest that the assistance of local scientific societies would be of little use, and the view has been expressed that such work is hardly likely to prove attractive to the ordinary members of local natural history societies as such : the method of approach is different and the work involves probing into and struggling with the complexities of human relationships from which many people are seeking relief in the contemplation of nature. I think these opinions are sound. It has been suggested that any requirements on these lines could be met by the formation of local societies of an entirely new type. There is no reason why there should not be : it is purely a matter of expediency. Unless a scientific society already has a section dealing with psychology and economics, with their implications and complications, it would be unwise to extend its work in this way : certainly it is not natural history as generally understood, though I should be the last to deny this wide connotation.

The Geographical Association has put forward a concrete proposal : they would welcome opportunities of collaborating with other societies in the preparation and publication of local regional surveys, if possible from all parts of the country. It is believed that such surveys would be valuable for teachers of history, geography, as well as science, apart from their wider general interest. As our Secretary has pointed out, it is relevant to note that it was the custom of the British Association before the last war to arrange for the publication of Scientific Surveys of the areas surrounding large towns where Annual Meetings were held. It was intended to produce progressively in a uniform series, surveys covering large areas of the country, for it normally takes about twenty-five years for the British Association to complete its circuit, and the progress in this respect is therefore slow. Moreover, there are many towns such as Shrewsbury, Northampton and Lincoln, which are not big enough to accommodate the Association.

These Surveys were excellent summaries, and a series covering the whole country would be a valuable mine of useful information. They are only summaries however. What should, I think, be aimed at by all natural history societies would be the construction of detailed vegetational maps of the districts covered by them and their use as a basis for distributional studies of every group of organism. Here it is of interest to note that the first vegetational maps published in Britain were by the brilliant young Dundee botanist, Robert Smith (1873-1900) and were intended eventually to comprise a 'Botanical Survey of Scotland.' The first was of the Edinburgh District (Midlothian and the Tay Basin) the second of North Perthshire (1900). A relief map based on that of the Edinburgh district is displayed at the Technical College here. This line of research was carried on by his brother, W. G. Smith, at Leeds, and through his stimulus the Central Committee for the Survey and Study of British Vegetation was formed in 1904 (the forerunner of the British Ecological Society, founded in 1913) and its members published several of these maps, but on a small scale which necessitated considerable generalization. I know that at least in his study of the 'Vegetation of the Peak District,' the late C. E. Moss used six-inch maps in the field, and this is a convenient scale for mapping the broad details of vegetation, though unwieldy. Perhaps the new three-inch maps would better serve the purpose, as they are large enough to give the borders of fields. Continued study over the years would provide facts about changes in vegetation, about the effect of these on the fauna and *vice versa*, and much precise information about habitats. Geology and types of soil obviously have a fundamental place in such investigations. Meteorological studies would contribute their quota, not only on time and period of flowering of

plants, but on populations—the abundance of a species of plant, for example, may be controlled by insect pests or fungus diseases, which themselves may be related to climatic conditions. There is abundant scope for the study of biotic factors. Competition amongst organisms is a necessary assumption in biology and was clearly stated by Linnaeus. It is, however, one of the most complicated problems and calls for the combined observations of naturalists of every kind. Detailed records will give a clue to what is happening : the correlation of observations on different groups will often suggest how it happens : the relation of these to soil, climatic and biotic factors would solve many problems.

In Scotland the 'Bathymetrical Survey of the Scottish Fresh Water Lochs,' published in five volumes under the general editorship of Sir John Murray and Laurence Pullar in 1910, contains many sections of great biological interest. George West, Lecturer in Botany at Dundee, wrote ' An epitome of a comparative study of the dominant Phanerogamic and higher Cryptogamic flora of aquatic habitat in seven lake areas of Scotland.' Would it not be worth while to study what changes have taken place since 1910—and are taking place at present—and try to account for them? The effect of pollution on the flora and fauna of rivers and lakes is of both scientific and economic interest : effluents from a Penicillin factory, for example, will cause the appearance of ' sewage fungus ' with its attendant ill effects on other organisms.

Such investigations necessitate a body of competent observers and an overall plan on a proper basis. To be most effective there should be co-ordination between societies and this would probably best be begun through a correlating committee of the various Unions. It has been proposed that Unions should be united on a national basis. ' A national council would seem to be a logical development, but in its absence, the British Association might usefully take steps to secure the appointment of a representative committee with functions of co-ordination and guidance.' This is a matter which should be discussed. But there should also be a scheme by which the number of competent observers could be enlarged, for probably even with proper direction they would prove far too few. Perhaps it will be better to return to this later. I should stress that my view is that there should be as much co-operation and co-ordination as possible but not centralisation. Any attempt at regimentation no matter what ' congeries of higher ups ' takes it in hand, would certainly do much harm and no good. Societies have their own individualities—the aim should be to develop these, not extinguish them.

Societies were asked whether it would be useful if panels of lecturers were prepared. The replies fall into two broad categories (a) those from large societies and near large centres, particularly near a University, who have no difficulty in drawing up their programmes,[1] or even in providing lecturers for schools and adult organisations, and (b) those from others, particularly in country districts, who would welcome assistance : these are in the majority. There are some exceptions to the first group, which, though near large centres, would, nevertheless, be glad of help. As very few of the societies under (b) have adequate funds for lecturers' expenses, regional rather than national panels are favoured. Two replies stressed a view which falls into line with the general trend of the ideas which I have formed. Though agreeing that such regional panels would be of value they are anxious that their societies should not ' degenerate' into groups of people meeting to listen to lectures, and regard it as important that natural history societies should be encouraged to rely to a great extent on their own members for lectures and for leadership of field meetings.

There can be no doubt that a programme with a list of prominent lecturers tends to attract a large audience—in well populated centres audiences so large that fees adequate to entice such lecturers can be paid : they are in fact public lectures. Such societies have their own members thoroughly competent to lecture, but the aim here is essentially that of attracting the general public : it is educational, it brings subjects to the notice of many who would not otherwise have the incentive to give them a thought. My remarks chiefly concern natural history societies, but many of you represent societies much wider in scope, or sometimes not directly concerned with natural history. It is obvious that many lectures must be purely informative. To take an example : I remember hearing a brilliantly simple exposition on nuclear physics by Lord Rutherford, at a Sunday afternoon meeting of the Ancoats Brotherhood—the charge of admission being a penny—and many will agree that it is possible to give an understandable account of the underlying principles of almost any scientific subject. It needs a certain aptitude ; the B.B.C. lecturers sometimes do it very successfully, and there are certain

[1] The influence of environment on a local society has been most clearly brought home to me since the delivery of this address. A scientific society has recently been formed at Richmond, Surrey. So many scientists reside, or are employed, in the district that the problems of arranging a lecture programme are merely those of convenient dates and balance.

scientists whose popular writings are excellent, not writing down to what is sometimes thought to be the level of general intelligence, but treating it with proper respect.

One may assume that the larger societies of this kind have sufficient members and funds to ensure that the other aspects of their legitimate activities are not neglected. Perhaps an additional one that might be suggested is that they should take an interest in the activities of any neighbouring local societies.

It would seem advisable for local natural history societies not to attempt to emulate the larger societies in having 'all star' programmes. Lectures by their own members on the aspects of nature study in which they have specialized helps to encourage others to take up investigations: moreover, it encourages younger members, for it sets them a standard of achievement obviously attainable—an occasional eminent lecturer may act as a stimulus to higher things.

The practice of having exhibits before the main item in the programme can be both instructive and stimulating: there is the exhibit of special interest because of its rarity and calling for some comment, but there is also the exhibit which might be arranged showing named common organisms.

It is obvious that the farther away lectures are from text books the more likely they are to have real value. Would it not be advantageous to have occasional lectures devoted to methods of identification? How many Honours students in botany in the past left an English University knowing what were the standard systematic works in the different groups or knowing how to set about using them, or the simplest points about nomenclature? Doubtless the interest in Ecology is changing this somewhat, but in suggesting ecological studies as likely to give local natural history societies scope for activities, I have in mind a wider concept than that which is generally current. Perhaps I should be better understood if I said ecological taxonomy with lectures devoted to the principles and practices in classification, would be helpful and stimulating; the field work, as I have already suggested, would be the naming and recording of organisms of all kinds, attempting to relate them to the environment of which they form a part—acting upon and reacted upon.

Other matters which were raised were the possibilities of joint subscriptions for more than one society and whether it would be advantageous to share accommodation and services. To the first the general opinion is that as each society fixes its subscription at the most reasonable economic figure there seems small scope for collaboration of this kind. Visitors from other societies are welcomed at meetings of some societies, and it has been suggested that a formal arrangement might be made by providing facilities for visitors to be put into touch with the secretaries of societies. There is apparently not much opportunity for the sharing of rooms and services, for the secretaries of most societies conduct their business in their own homes or some institution to which they are attached.

The last of the questions concerned publications, but the remarks made on this were few. For instance, the only definite replies about standard size of publications, recommended two different schemes: $11\frac{1}{2}'' \times 8''$ and $9'' \times 6''$ (Aslib) and $9\frac{3}{4}'' \times 7\frac{1}{4}''$ (Congress of Archaeological Societies).

One correspondent referred to many transactions of local societies as being 'an irritating mixture of ephemeral and valuable contributions,' and proposed a separate publication of the valuable material; he also recommended the circulation to editors of a guide on format based on the best standards of presentation, such as are occasionally issued by periodicals to intending contributors.

Whether or not a given article is worth publishing depends upon the purpose of the periodical and the standard set. If the aim is to provide an account of a society's activities then there will obviously be much that to strangers may appear trivial. On the other hand if too high a standard is set the periodical will tend to become a scientific journal with little or no relation to the *activities* of the society. One must recognize, however, that some excellent papers tend to be overlooked if published in this way, and it would be advantageous to issue lists of important papers as was done formerly in the British Association Reports. It would be extremely useful in several ways if a selection of the papers most likely to be consulted could be republished in an annual volume, but the basis of choice would need careful consideration. Many systematists are mainly interested in new records, and they fear that these will be overlooked in local society publications. It should be easy to arrange for all editors to send a note about such records to a central body: there is no need to re-issue a paper on that ground alone. The Royal Society might be asked to allot money for the purpose from the Treasury fund they administer.

Most societies find present printing costs to be a serious matter, even prohibitive. Some societies are overcoming their difficulty by arranging for lectures and reports to be published in the local press and obtaining reprints. The difficulties unfortunately are common to all. Ingenuity may find

temporary ways of overcoming them, but I feel that if the local societies may be said to be fulfilling their functions the troubles may not be insoluble.

I must express my thanks to the Secretary of the Association for supplying me with a summary of the replies to the circular letter. I have dealt with them all, either in the course of my general remarks or specially. Though I have had no practical experience as secretary of a local natural history society, close contact with several of these both privately and officially, makes me fully realise the sense of frustration under which some of them carry on. As has doubtless been gathered from my remarks, I am convinced that with co-ordination and co-operation results of such value can be achieved, both in education and research, that the local natural history society will take its proper prominent place in our national life.

By custom a President's Address is sacrosanct from immediate criticism. I trust, however, that there will be full and free discussion of the points that have been brought forward, and that from it we may reach some definite conclusions which may be pressed to practical benefits.

DEPLETION OF WILD ANIMAL POPULATIONS [1]

By

Prof. JAMES RITCHIE

Interference with wild animal populations, sometimes deliberate, more often indirect and unconscious, has been an inevitable result of the developments of the war years, and is likely to continue if not to be intensified in the developments of the years of peace. This has been painfully obvious to all interested in the wild life of our country. But to grasp the significance of this process of wild life depletion, and thus to establish the need for rapid action—not to stem the tide of interference, for its flow is as inevitable as the progress of civilisation, but to avoid its worst effects upon wild animals—it is desirable to glance at the new features which make the preservation of animal life one of the most pressing problems of the present-day naturalist.

Depletion of animal populations is no new occurrence in the history of nature. It has marched almost step by step with the progress of evolution, and it has resulted from diverse causes, the broad effects of which, from the present point of view, may be summed up quite simply. In the long past, extermination on occasion came suddenly, wiping out whole populations in one deadly catastrophe ; so fishes of the fresh-water lakes in the Scotland of the Old Red Sandstone period were blotted out, for their remains, entombed in the flagstones of Caithness or the yellow sandstone of Dura Den in Fife, lie in great assemblages at definite horizons. But as a rule geological extermination may be regarded as a slow process, due to secular changes which, slowly as they altered climate and vegetation, yet exceeded the rate of the organic response and adaptability of some types of animal life. So the Dinosaurs and many other forms had come and gone long before Man made his belated appearance on the Earth ; but no one believes that these creatures disappeared rapidly, that is to say in the course of a century or two, or even in a millenium or two—though that is a considerable span in the view of human generations.

I have no doubt that if Man had not arisen to crown the Anthropoid stem, the world of nature would have pursued its comings and goings at its own leisurely pace, and slow depletion of old populations and tardy development of new populations would have been part of its normal routine. The coming of Man, however, initiated new kinds of interference with wild life, the ultimate effect of which has been to speed up processes of destruction, the issue of which was formerly reckoned in aeons. The great and simple fact about the impact of humanity upon wild life is that it has increased the *tempo* of change, whether the change be one of depletion or one of increase of populations. But the great and simple fact is not the whole truth, for the most significant thing about Man's interference is that the *tempo* of its operations has not remained constant ; and the scientific basis for immediate, drastic and deliberate intervention, this time on behalf of the threatened populations, must rest upon an analysis which from past events forecasts the likely future of wild life in a man-controlled world.

Some aspects of that analysis I dealt with in my Presidential Address to the Zoology

[1] The text of a paper given by Professor Ritchie in opening a discussion arranged by Section D (Zoology) at Dundee on August 29, 1947. Notes on the other papers follow at the end.

Section at the Dundee Meeting in 1939. I pointed out that, estimating the existence of Man (i.e. *Homo sapiens*) upon the earth at round about 50,000 years, for a matter of approximately 40,000 years, 80 per cent. of that period, his activities had little more effect upon wild animals than those of the creatures with whom he shared the jungle. That is to say that Man's first serious impact upon wild life was due to his outstanding achievement in domesticating a few wild animals and in developing the cultivation of the soil and the growing of crops, and those achievements of the Neolithic Period were the foundation of a series of gross interferences with wild nature, which, generally speaking, have increased with each extension and intensification of the practice of agriculture.

Industrial development stands alongside agriculture as a second overwhelming influence upon wild life, and again the pressure has increased and effects have intensified and multiplied with the progress of industry. That is the point to which I particularly wish to draw your attention ; Man's interference with wild life has been progressive and its rate of progress has steadily increased and is still increasing. It is like a fire which, having smouldered unnoticed for many thousands of years, suddenly bursts into flame and, spreading by leaps and bounds from one centre to others, threatens now to leave no aboriginal assemblage of plants and animals unscorched.

In a very general way we can measure the sweep of this conflagration, and we are bound to be astounded at the amazingly short period of time, relative to Man's existence upon the Earth, during which his interference has been fanned into a destroying blaze. In an address at Ann Arbor on one occasion, Raymond Pearl gave a clue to the opening of this critical period in Man's relations to wild nature. He pointed out that, over the whole period of Man's existence upon the earth, the number of human beings had increased so slowly that by the middle of the seventeenth century the world population, on generally concordant estimates, was of the order of no more than 450 million persons. But since then, during the last 300 years, 'Mankind has increased its numbers by just short of five-fold, a truly colossal ratio as compared with his previous growth performance record.' Now, this remarkable increase is due to just those factors which impinge upon wild life from so many angles—intensified agriculture and stockrearing ; the spread of industries ; the development of internal commerce with its roads penetrating hitherto undisturbed country-side ; its international counterpart transporting across the continents and across the seas representatives of the wild life of every country, which have striven, often without success, but sometimes with disastrous efficiency, to compete with the established inhabitants of other lands.

Look upon the Man-made changes, in wild-life populations throughout the world, which stare us in the face today—disappearance of many species, the curtailment of numbers due to the invasions by cultivation and domestic animals of former wild habitats, the increase of pests encouraged by a bounteous agriculture, and not least the establishment of 'foreign' creatures introduced accidentally or deliberately into stabilised faunas. These changes have altered some faunas beyond recognition, they have left, even now, scarcely a fauna in the world in its truly aboriginal state ; but the vital point is that, in some 300 years, Man has profoundly modified by drastic interference the assemblages which wild nature had evolved in its leisurely millions of years. Man has placed a violent foot upon the accelerator, and there is no brake on this Juggernaut's car of destruction.

The pace of depletion of wild populations, serious as it has become, is quickening. Glance at the world position as regards the mammals.

First as regards extinction. In all the years from the opening of the Christian Era to the end of the eighteenth century, 33 species of mammals are known to have become extinct—33 extinctions in 1,800 years. But in the next century, the process was greatly accelerated, for in the hundred years from 1800 to 1900, the number of extinctions was also 33, and of these it is noteworthy that the vast majority occurred during the second half of the century. Since then there has been no let-up, indeed further acceleration is obvious. Francis Harper, from whose account of *Extinct and Vanishing Mammals of the Old World* (1945) I have taken these figures, has brought the statistics up to 1944, and he records the disappearances of mammalian species and sub-species, in these forty-four years of the present century, as 40—almost one distinctive mammal blotted out every year. Thirty-eight per cent. of the total losses since the opening of the Christian Era have taken place in the present century.

Extinction by itself, however, does not give an adequate picture of the danger which threatens mammals and other wild creatures. Extinction is the final result of a lengthy process which entails reduction of numbers, restriction of range and so on. Perhaps a stronger urge to action will be found in considering those about to die, rather than those already dead. Here again the figures are impressive. The late Glover Allen, in his

Extinct and Vanishing Mammals of the Western Hemisphere (1942), placed over 200 species and sub-species of New World mammals on the list of extinct or in danger of extinction ; and the corresponding number in Francis Harper's work on the Old World is roughly 370 ; so that throughout the world there are between 500 and 600 mammals whose continued existence almost certainly depends upon special efforts at protection.

The present position, therefore, is that, throughout the world as a whole, Man-made pressure upon animal communities has increased to a degree hitherto undreamed of. And if we look at our own country as an example, there are evidences of extending interferences with wild life, the inevitable results of which will be further and still more rapid depletion of wild faunas. There are the rapidly extending suburbs of our great cities encroaching upon new territory, and the proposed planting of new townships in what was all but open country. There are the new industrial estates, with their roadways and communications, and all the bustle and disturbance of the traffic of multitudes of human beings, breaking in upon the peaceful habitats of the country-side. Many of these habitats have already been taken over and modified, if not destroyed, so far as native flora and fauna go, for the training grounds of His Majesty's Forces. Every change wrought upon the country-side—its hills, its moors, its sand-dunes, its rivers and lakes—by afforestation, by water-catchment schemes and hydro-electric developments, by land-drainage and all the rest, is bound to produce drastic and unforeseeable alterations in the assemblages of wild life as they exist today.

In addition, the peculiar conditions of our times have introduced new and less obvious influences, which add quite notably to the sum of disturbance. To take one example ; the scarcity and rationing of butcher's meat has placed a premium upon the slaughter of wild fowl. Advertisements have actually appeared in Scottish newspapers offering substantial prices for the carcases of birds, some of which in the past would scarcely have been regarded as edible. Here is a sample of such a demand from a Shetland newspaper : ' Prices of Wildfowl. An Opportunity to Augment Incomes '—Gannets 3*s.* 6*d* ; Divers 1*s.* 6*d.* ; Cormorants 3*s.* ; Eiders 3*s.* 3*d.* ; Silver Plover 1*s.* 6*d.* ; Redshank 1*s.* 6*d.* ; Oyster-catchers 1*s.* The results of such inducements cannot well be estimated, but it is on record that in Leadenhall Market on 17th December, 1946, there were exposed for sale eighteen cases of Eider Duck, with about 20 birds in each case, and that in this instance all these birds had been consigned from a county in which the Eider Duck is scheduled as protected throughout the year.

What is the lesson to be drawn from this tale of increasing depletion of wild life? Obviously that wild life almost everywhere is in need of immediate protection. But it is equally obvious that, since the disturbance of wild life is directly correlated with the progress of civilisation, it cannot be stopped and it is bound to increase extensively and intensively. The situation, however, is not hopeless. A little may be done by legal enactments, provided the law is enforced with vigour. Much may be done by instilling, by educational methods, an active interest in wild life and an appreciation of wild life as a national heritage. But the most promising method is trying to preserve for the future samples of the wild-life populations of to-day, since the preservation of *all* wild life as it is now is beyond the power of Man. The samples may be preserved in special areas set aside because they represent types of country with their characteristic assemblages of plants and animals. And the establishment and maintenance of wild-life sanctuaries and nature reserves is just the naturalist's device for side-stepping some of the effects of civilisation upon the old-established order of wild nature.

Professor Ritchie's statement on the present status of this problem in the world as a whole was followed by a series of papers on particular aspects of it. Dr. Frank Fraser Darling spoke on mammals in Great Britain, Prof. Dr. G. J. Van Oordt on the effect of bird protection on population numbers in the Netherlands, Dr. J. Berry on freshwater fisheries and Dr. G. C. L. Bertram on marine fisheries.

Dr. Van Oordt said that, as a result of better protection measures, many bird species, especially Gulls, Sandwich Terns, Cormorants, Eider Ducks etc. had increased in number in the Netherlands in recent years. As a consequence, however, several species such as Shelduck, Common Tern, etc. had suffered and were nowadays present in smaller numbers than formerly. He reported exact data on the increase or decrease of several species from about 1929 onwards and stressed the fact that it was necessary to control the increase of some species : it might even be urgently necessary to take the strongest possible measures of control.

Dr. Berry discussed the possible effects of hydro-electric development on the stocks of salmon and trout. He said that over-fishing of salmon and migratory trout had been arrested by restrictive legislation, and the danger from this source was not now

serious. What was serious, however, was the menace of destruction of the stocks by pollution, particularly from industrial effluents ; unfortunately this menace still continues.

In recent years, apprehension has been expressed lest the plan for comprehensive hydro-electric development of the Highlands should destroy the salmon and trout in many still productive lochs and rivers where pollution is unknown.

Hydro-electric operations can affect salmon by altering the accessibility and nature of the spawning grounds ; by altering the rearing and feeding conditions for young fish and their liability to destruction by predatory enemies and disease and by impeding the seaward migration of the smolts. But it is not only possible in most cases to avoid the damage to the fisheries which ill-planned hydro schemes may do : hydro schemes can actually benefit the fish. The new hydro-electric projects in the Scottish Highlands are being planned, so far as practicable, with this end in view : and they provide unique opportunities for fundamental research.

In discussing the depletion of marine animals Dr. Bertram said that there was great pressure on the environment exerted by two thousand million hungry *Homo sapiens* who were fast increasing in numbers. A part of man's food and other requirements comes from the sea by the exploitation of animal stocks. The most important of these stocks are vertebrate, and their exploitation in general shows Man still in the hunting phase of his development. Many populations of marine vertebrates have been, and are being depleted in spite of valiant attempts at proper conservation. Dr. Bertram dealt in particular with the depletion and exploitation of seals, whales and fish and drew attention to those instances where rationality and/or increase in numbers had been, or seemed likely to be, achieved. He also pointed out that, in the long run, rational utilization generally corresponds with proper economy in money and man power.

MATHEMATICAL TABLES

REPORT of COMMITTEE on Calculation of Mathematical Tables. Dr. A. J. Thompson, *Chairman* ; Dr. J. Wishart, *Vice-Chairman* ; Dr. J. C. P. Miller, *Secretary* ; Prof. W. G. Bickley, Dr. R. O. Cashen, Prof. R. A. Fisher, F.R.S., Dr. J. Henderson, Dr. J. O. Irwin, Prof. L. M. Milne-Thomson, Prof. E. H. Neville, Mr. D. H. Sadler, Mr. F. Sandon, Mr. W. L. Stevens, Mr. John Todd, Mr. M. V. Wilkes, and Mr. J. R. Womersley. [Report presented in September 1947].

This report covers eight years, the period that has elapsed since the last report (1939). A report was prepared for August 1940, but was not presented, owing to the illness of the Chairman ; a report covering two years was prepared and presented in 1941, but remains unpublished. The present report incorporates these.

General Activity.—Two or three meetings were held each year throughout the war period ; with the end of the war greater activity has been resumed and thirteen meetings have been held during the last two years. All meetings have been in London.

Contingent grants of £100 (1939), £50 (1940), £25 (each year 1941–45) and £80 (1946) were made. The amount expended was £207.

Personnel.—The Committee reports with great regret the death of three of its members.

Dr. E. L. Ince, who died on 16th March, 1941 first came into touch with the Committee as computer of their fourth published volume, *Cycles of Reduced Ideals in Quadratic Fields*. As stated in the preface to that volume, the Committee was peculiarly fortunate in being able to enlist his services for a task he was almost uniquely qualified to perform ; mathematical ability, typographical skill, meticulous attention to detail, accuracy, and immense industry are combined in a scholarly table which is Dr. Ince's best memorial in this field. From the completion of this table until his death Dr. Ince was a zealous member of the Committee, which profited on many occasions by the range of his mathematical knowledge and by the independence of his judgment.

Mr. Frank Robbins died on 4th May 1945, at the age of 84. He joined the Committee in 1930 and attended meetings with exemplary regularity until prevented by illness and weakness. He was a willing and industrious proof-reader, and the Association is indebted to him for a valuable share in the anonymous work which is in the background of all the publications of the Committee.

Dr. J. F. Tocher died on 8th November 1945. A man of wide and varied interests, he found himself engaged early in life on statistical computations in connection with Karl Pearson's population studies. He attended regularly the annual meetings of the Association, and it was at Glasgow in 1929 that he was invited to join the Committee. He lived too far away to attend the meetings of the Committee in London, but its work always interested him.

Dr. R. O. Cashen (formerly, as Mrs. Tysser, the Committee's computer), Mr. John Todd and Mr. J. R. Womersley have been co-opted to the Committee.

Chairmanship.—Prof. E. H. Neville resigned in January 1947. He was succeeded by Dr. A. J. Thompson.

Secretaryship.—Dr. John Wishart resigned in January 1946. He was succeeded by Dr. J. C. P. Miller.

Computing.—For the first eight months of the war, computing progressed steadily, the computer and machines accompanying the Galton Laboratory in its evacuation to Rothamsted. In April 1940 the National Machine was leased to the Government. Dr. Cashen at the same time obtained employment elsewhere. The Committee records intense appreciation of Dr. Cashen's work, both as computer and as clerical assistant to the Secretary ; she joined the Committee to continue voluntarily the latter services and carried them on almost single-handed while the Secretary was fully occupied with war-work.

The lack of a full-time computer for most of the war-time period brought to a standstill the progress on routine computations for the Committee's second volume of Bessel functions. As the need for these tables became apparent, requests for the available material were met by photostat copies. It became clear, however, that completion was desirable for war-time purposes, and in March 1944 the Admiralty Computing Service offered to complete the routine subtabulation and preparation of printer's copy for this volume. This offer was gratefully accepted, and the copy has now been completed.

Throughout the war exploratory investigations and computations were continued, as circumstances permitted, by individual members of the Committee. Indebtedness to Mr. C. E. Gwyther for indefatigable help with these computations is again expressed with pleasure.

During the summers of 1939 and 1940, and again in 1946 and 1947, further work was done under the supervision of Dr. Miller at Liverpool, and the Committee again records its appreciation of the facilities offered by the Mathematical Laboratory of the University of Liverpool. At the end of the war, Prof. L. Rosenhead, F.R.S., on behalf of the University, offered to house the Committee's National machine in the Mathematical Laboratory, on its return by the Government. This offer was gratefully accepted, and the machine is now installed there.

Publications.—The tables published since the 1939 report are as follows :—

Volume VIII.—*Number-Divisor Tables.* Pp. x, 100. 1940. These are the tables described in the Committee's 1939 report as Glaisher's Tables. Since the functions are not due to Glaisher or associated by mathematicians with his name, a descriptive title has been substituted. The Volume was prepared by Prof. D. H. Lehmer and Dr. Wishart, and edited by Dr. Wishart.

Volume IX.—*Table of Powers.* Pp. xii, 132. 1940. This was edited by Dr. Miller. Details have appeared in the reports for 1936 and 1939.

Volume I.—*Circular and Hyperbolic Functions, etc.* Second edition. Pp. xii, 72. 1946. The first edition of this volume was exhausted in 1941. Dr. Henderson, Prof. Milne-Thomson, Prof. Neville and Mr. Sadler were appointed a sub-committee to prepare an emergency edition, in which, to save paper, the preliminary matter was reduced from 36 to 12 pages. An extension of Prof. Fisher's table of the factorial function from 12 to 18 decimals by Mr. S. Johnston is included.

Part-Volume A.—*Legendre Polynomials.* Pp. 40. 1946. Prepared by Dr. L. J. Comrie, edited by Dr. Thompson. The tables described in the report for 1936 have been extended by the editor to include $P_n(x)$ for $n = 10$, 11 and 12 and $x = 0(0{\cdot}01)1$.

Part-Volume B.—*Tables of the Airy Integral.* Pp. 56. 1946. Prepared by Dr. Miller. These tables give two independent solutions of the differential equation $y'' = xy$ to 8 decimals. The first solution $\mathrm{Ai}(x)$ is tabulated for $x = -20(0{\cdot}01)+2{\cdot}5$ and auxiliary tables extend the range for which values can be obtained to $x = -80$ to $+75$. The second solution $\mathrm{Bi}(x)$ is tabulated for $x = -10(0{\cdot}1)+2{\cdot}5$ and the range is extended by auxiliary tables to $x = -80$ to $+10$. In each case the first derivative is also tabulated and provision is made for interpolation, by means either of differences or of reduced derivatives. Tables connected with the zeros of the two solutions are also included. The tables were prepared at the suggestion of Prof. H. Jeffreys. The volume includes a diagram giving graphs of the various functions ; the block for this was kindly lent by Dr. L. J. Comrie.

Auxiliary Tables.—Number I. *Coefficients of the Modified Everett Interpolation Formula.* 1 page. Number II. *Table for Interpolation with Reduced Derivatives.* 2 pages. 1946. These were prepared for use when interpolating the Airy Integral Tables. They are printed on stiff card, and a copy of each is included with Part-Volume B ; they are also available separately.

Volume II, *Emden Functions*, Volume VI, *Bessel Functions, Part 1*, and Volume IX, *Table of Powers*, are now out of print. The stock of Volume I, second edition, is almost exhausted.

Bessel Functions. As stated earlier, the whole of the tabular material for *Bessel Functions, Part 2*, has been completed, and is in the press ; most of the first proofs have been received. The volume will include two series of tables. The first set of four tables will give values of the standard Bessel functions, or of auxiliary functions, to 8 figures (8 decimals for $J_n(x)$) with second differences, the function and interval of tabulation being so chosen that these differences suffice for interpolation. These tables are

(1) $J_n(x)$, for	$n = 2(1)20$	and	$x = 0(0{\cdot}1)25$
expanded for	$n = 2(1)12$	to	$x = 0(0{\cdot}01)10$
and for	$n = 13, 14, 15, 16$	to	$x = 0(0{\cdot}01)6{\cdot}5$, 6, 5, 5 respectively.
(2) $Y_n(x)$ or $y_n(x) \equiv x^n Y_n(x)$, for	$n = 2(1)20$	and	$x = 0(0{\cdot}1)25$
expanded for	$n = 2(1)11$	to	$x = 0(0{\cdot}01)10$.
(3) $e^{-x}I_n(x)$ or $i_n(x) \equiv x^{-n}I_n(x)$, for	$n = 2(1)20$	and	$x = 0(0{\cdot}1)20$
expanded for	$n = 2(1)11$	to	$x = 0(0{\cdot}01)5$.
(4) $e^{x}K_n(x)$ or $k_n(x) \equiv x^n K_n(x)$, for	$n = 2(1)20$	and	$x = 0(0{\cdot}1)20$
expanded for	$n = 2(1)11$	to	$x = 0(0{\cdot}1)5$.

The second set of four tables will give 10-figure values (10-decimal values for $J_n(x)$) of the standard Bessel functions, without provision for interpolation. These tables are

(5) $J_n(x)$ for	$n = 0(1)20$	and	$x = 0(0{\cdot}1)25$.
(6) $Y_n(x)$ for	$n = 0(1)20$	and	$x = 0(0{\cdot}1)25$.
(7) $I_n(x)$ for	$n = 0(1)20$	and	$x = 0(0{\cdot}1)20$.
(8) $K_n(x)$ for	$n = 0(1)20$	and	$x = 0(0{\cdot}1)20$.

This volume is being edited by Prof. Bickley.

It is proposed to issue a second edition of *Bessel Functions, Part 1*, to appear at the same time as *Part 2*.

Bessel Functions of Order $\pm\frac{1}{4}$ *and* $\pm\frac{3}{4}$. The seven-figure tables of $J_n(x)$ for $n = \pm\frac{1}{4}, \pm\frac{3}{4}$, mentioned in the report for 1933, have been extended to give values for $x = 0(0{\cdot}01)5(0{\cdot}1)20$. Similar tables of $(2/\pi)K_n(x)$ for $n = \frac{1}{4}, \frac{3}{4}$ are under construction, and permission has been sought to include tables of $I_n(x)$ for $n = \frac{1}{4}, \frac{3}{4}$ computed under the direction of Dr. A. N. Lowan by the National Bureau of Standards (formerly New York) Mathematical Tables Project. Other functions of order $\pm\frac{1}{4}, \pm\frac{3}{4}$ will not be included, since $Y_n(x)$ for $n = \pm\frac{1}{4}, \pm\frac{3}{4}$ are linear functions of the $J_n(x)$, while $I_n(x)$ and $(2/\pi)K_n(x)$ for $n = -\frac{1}{4}, -\frac{3}{4}$ can be expressed linearly in terms of the functions of positive order.

Extension of Meissel's Table of $J_n(x)$.—Meissel's table (see Gray, Mathews and MacRobert, *A Treatise on Bessel Functions*, 1922, p. 286) gives $J_n(x)$ for $x = 1(1)24$ and $n = 1(1)N$, where N is such that $J_{N+1}(x)$ is less than half a unit in the 18th decimal; values are to 18 decimals. This table is being extended by Dr. Miller and Mr. C. E. Gwyther to cover the range $x = 0(1)80$, and for $n = 0$ and 1 only, $x = 81(1)100$. A similar table of $Y_n(x)$ for the same values of x and for n up to 30 or more is almost complete.

These tables were computed to facilitate the evaluation of zeros of $J_n(x)$ by means of a series depending on $J_n(x_0)$ and $J_{n+1}(x_0)$, where x_0 is an approximate value for a zero, but they have an independent usefulness of their own. The calculations have been continued to introduce similar, but less extensive, tables of $I_n(x)$ and $(2/\pi)K_n(x)$ to about 15 figures.

It is proposed to publish these tables as *Bessel Functions, Part 3*.

Bessel Function Zeros.—It was originally intended to give tables of zeros of $J_n(x)$ and $Y_n(x)$ in *Part 2*, but computational difficulties have led to the decision to postpone them for a *Part 4*, which it is proposed shall also contain zeros of the derivatives of $J_n(x)$ and $Y_n(x)$ and corresponding turning-values of $J_n(x)$ and $Y_n(x)$. It is also proposed to include values of

$$J'_n(x) = J_{n-1}(x) = -J_{n+1}(x) \text{ and of } Y'_n(x) = Y_{n-1}(x) = -Y_{n+1}(x)$$

corresponding to the zeros of $J_n(x)$ and $Y_n(x)$ respectively.

It is further proposed to include zeros for non-integral values of n, while the inclusion of zeros of such combinations as

$$J_n(x)Y'_n(kx) - Y_n(x)J'_n(kx)$$

is under consideration.

Investigations into methods for computing and checking these zeros have been carried on throughout the war. Results of some of these investigations are given in a series of five papers, by Prof. Bickley, Dr. Miller and Mr. C. W. Jones, *Phil. Mag.* (7) **36**, 121–133, 200–210, 1945.

Circular Functions for Argument in Degrees and Decimals.—Of the three main systems of subdivision of the quadrant, the best established and commonest is the sexagesimal. It has, however, very obvious disadvantages, and these have led to the introduction of alternatives. Of these, the centesimal and degree-decimal subdivisions, the more generally useful would seem to be the latter. Circular functions with the argument in this form have, however, been somewhat neglected by table-makers since the appearance of Briggs's table in *Trigonometria Britannica*, 1633. This applies particularly to tables giving natural values to eight or more figures. The Committee considers that a table to many figures, with provision for interpolation, giving natural values of the sine and cosine for arguments $0°(0°{\cdot}1)45°$ would be opportune; such a table is being prepared by Prof. Neville.

Confluent Hypergeometric Function.—Further theoretical and numerical work has been done by Dr. Thompson on this function, which (see Reports for 1927 and 1928) is here defined as

$$M(\alpha,\gamma,x) = 1 + \frac{\alpha}{\gamma}x + \frac{\alpha(\alpha+1)}{\gamma(\gamma+1)}\frac{x^2}{2!} + \frac{\alpha(\alpha+1)(\alpha+2)}{\gamma(\gamma+1)(\gamma+2)}\frac{x^3}{3!} + \cdots$$

and on the associated function

$$N(\alpha,\gamma,x) = \frac{\alpha}{\gamma}\left(\frac{1}{\alpha} - \frac{1}{\gamma} - 1\right)x + \frac{\alpha(\alpha+1)}{\gamma(\gamma+1)}\left(\frac{1}{\alpha} + \frac{1}{\alpha+1} - \frac{1}{\gamma} - \frac{1}{\gamma+1} - 1 - \tfrac{1}{2}\right)\frac{x^2}{2!} + \cdots$$

Substantial progress has been made in the calculation of basic values of these functions, with a view to subsequent expansion into working tables for such values of the variable as may be required. Basic values are now available for $M(1,\gamma,x)$, $N(0,\gamma,x)$ and $N(1,\gamma,x)$ for $\gamma = 1(1)100$, $\pm x = 0{\cdot}5,1(1)10(10)50$, calculated mainly to 22 decimals—9000 values in all. Experimental tabulations of M and N for $x = 10$ are complete for

(i) $\gamma = 1$, $-\alpha = 0(0{\cdot}02)20(0{\cdot}1)100$; and
(ii) $\gamma = 2(1)50$, $\alpha = -1{\cdot}4$ to $+1{\cdot}4$,

both at interpolable intervals in α. The latter tables (ii) would serve as bases for the tabulation of M and N for $\gamma = 2(1)50$, and all negative values of α.

Cunningham Bequest.—Volumes VIII and IX were published by means of this bequest. Further tables planned are as follows :

Farey Series.—The Committee has accepted for publication under the Cunningham bequest a compilation by Prof. Neville of the Farey series of order 1025; this series has 319765 terms, and is arranged to occupy 400 pages. The series exhibits solutions of the linear Diophantine equation $bx - ay = 1$ for all values of a and b not exceeding 1025, and furnishes the closest rational approximations within the same order to any number, rational or irrational, between 0 and 1. The introduction shows how by a process of local self-packing the series can be used efficiently to solve linear equations with coefficients of any magnitude and to find rational approximations of any order.

Partition Tables.—Prof. H. Gupta has offered to the Committee a table giving the number of partitions $p(n,m)$ of n into parts, the greatest of which is m. The table extends to $n = 200$, with m up to n or 50, whichever is less. It is recommended that this be accepted for publication. It is proposed to extend the table to $n = 300$ with m up to n or 100, whichever is less. Permission has been obtained to incorporate the published table by Dr. J. A. Todd, *Proc. Lond. Math. Soc.*, **48**, 229–242, 1943–44, which extends to $m \leqslant n \leqslant 100$. The extension is being carried out by Mr. C. E. Gwyther.

Coefficients in $\{F(q)\}^k$ *where* $F(q) = (1-q)(1-q^2) \ldots (1-q^m) \ldots$ It is proposed to evaluate the coefficients of the first 300 powers of q in the expansions for $\{F(q)\}^k$ for $k = 1(1)24(2)48$. Many of these coefficients have interesting multiplicative and other properties that have been investigated by Glaisher, Ramanujan and, more recently, by Lehmer, Mordell, Rankin, Watson and others. This table is being prepared by Dr. Miller and Mr. D. F. Ferguson.

Binomial Coefficients.—The preparation of a table of Binomial Coefficients is under discussion. In connection with this, a list of formulæ has been offered by Dr. S. Vajda. It is proposed that the table should give exact values of $\binom{n}{r}$, complete to $n = 200$, with extensions to higher values of n for $r \leqslant 12$.

Offers of Tables to the Committee.—In addition to the Table of Partitions, other tables, listed below, have also been offered to the Committee.

By Mr. W. E. Mansell. Tables of Common and Natural Logarithms to many places of decimals ; Tables of Interpolation Coefficients ; Tables of Binomial Coefficients ; Special Factor Tables, etc.

By Dr. R. C. Pankhurst and Dr. J. F. C. Conn. Table of Chebyshev Polynomials. This gives exact values of $C_n(x) = 2\cos n\theta$, where $n = 1(1)10$ and $x = 2\cos\theta = 0(0{\cdot}02)2$. The values for $n = 1(1)7$ and a 10-decimal curtailment for $n = 8(1)10$ have been combined with a table by Mr. C. W. Jones and Dr. Miller and published ; *Proc. Roy. Soc. Edinburgh*, **62**, 187-201, 1946.

Taylor Coefficients.—The attention of table-makers is invited to the need for a brief standard heading for columns of the Taylor coefficients $h^n f^{(n)}(x)/n!$. The Committee has adopted the heading τ^n, which, like δ^n and other headings, will be printed without the functional symbol and usually without indication of h, which is in practice always the interval of tabulation. The index notation may be justified by definition of τ as an operator :

$$\tau\varphi(x,h) = \int_0^h \frac{\partial\varphi(x,t)}{\partial x}\,dt$$

With this definition $\tau f(x+h) = f(x+h) - f(x)$

and therefore formally $f(x+h) = (1 + \tau + \tau^2 + \ldots)f(x)$

as required.

Outside Contacts.—The Committee has been in touch with Prof. R. C. Archibald, and has given details of the progress of its computations, particularly of Bessel functions, for publication in his periodical *Mathematical Tables and other Aids to Computation.* Contact has also been maintained with Dr. A. N. Lowan, technical director of the Mathematical Tables Project, originally set up by the Works Progress Administration for the City of New York and now conducted by the U.S. National Bureau of Standards. As explained above, an advantageous co-operation was arranged with the Admiralty Computing Service. Mr. Womersley, Director of the Mathematics Division of the National Physical Laboratory, which has taken over some of the similar computational staff of the Admiralty Computing Service, has agreed to similar co-operation. To meet war needs the Committee made available copies of certain unpublished material, either by photostat, by typescript, or, in the case of the Airy Integral Tables, by printed proofs.

Future of the Committee.—The Committee has given consideration to its future in the light of :

(i) the increased demand for, and interest in, mathematical tables ;
(ii) the inauguration of the Mathematics Division of the National Physical Laboratory and the development of University Mathematical Laboratories ;
(iii) the new statute of the Association restricting grants to research committees to a period of five years.

A memorandum on this subject has been presented to the Council in which the view is expressed that there exists an essential requirement for an authoritative body to exercise the following functions in the field of mathematical computation :

(*a*) Co-ordination of the activities of organisations engaged in calculating tables.
(*b*) Publication of fundamental tables of the highest standards of accuracy and presentation.
(*c*) Advice on the mathematical and computational aspects of tabulation and on the arrangement and presentation of tables.

It is suggested that the British Association has, in the Mathematical Tables Committee, a body that is qualified to fulfil all these functions, but it would be able to do so fully only if adequate financial provision could be made. To carry out these tasks efficiently, it is considered necessary that the Committee should, collectively and individually, be actively engaged in the calculation and preparation, as well as in the publication, of mathematical tables. Much exploratory and research work is usually necessary in connection with the inception and early stages of the Committee's projects, entailing non-routine computation of an elaborate character. Most of this has been, and would continue to be, done by members of the Committee and by other voluntary workers, but the provision of highly skilled paid computers, one at least a first-class mathematician, would greatly increase its efficiency and power.

As a first step towards the co-ordination of activities of the various bodies engaged in the calculation of tables, the Secretary has prepared a list of Fields of Tabulation in which the tabulation of functions is active, or in which there is a lack of adequate tables. It is proposed that this list be amplified by direct consultation with all the organisations concerned, and published in *Mathematical Tables and other Aids to Computation* as a guide to those who use, and to those who make, tables.

Reappointment.—The Committee desires to be reappointed, with the addition of Mr. C. W. Jones and Dr. E. T. Goodwin. A grant of £150 will be needed for carrying out effectively work on tables at present in hand and for secretarial expenses. In addition full use could be made of a full-time computer, in which case the total grant sought would be £500.

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